FACILITY FORM 602

N71 31604

(ACCESSION NUMBER) (THRU)

72 G3

(PAGES) (CODE)

CR-115114 31

(NASA CR OR TMX OR AD NUMBER) (CATEGORY)

CR-115114

17618-H175-R0-00

TRW NOTE NO. 61-FMT-876

PROJECT SKYLAB

TASK MSC/TRW AA-41

ENGINEERING DESCRIPTION
FOR
TACS-SM RCS CONSUMABLES PROGRAM

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1 July 1971

Prepared for
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NOMENCLATURE

ATM	Apollo Telescope Mount (also flag used to denote ATMDC control)
ATMDC	Apollo Telescope Mount Digital Computer
BAOPM	Beta Angle and Orbit Position Module
CMG	Control moment gyro
CSM	Command service module
ED	Event data
ERE	Earth Resource Experiment
EOT	SM RCS jet electrical on time
G	Gravity constant
GET	Ground elapsed time
GGDM	Gravity Gradient Disturbance Module
I_{SP}	TACS specific impulse
I_{SPCSM}	SM RCS specific impulse
I.U.	Instrument Unit
LV	Local vertical
MAMRM	Maneuver Angle and Maneuver Rate Module
MID	Mission independent data
MPM	Mass Properties Module
OA	Orbital Assembly
PDD	Program Definition Document
PVIS	Parametric Variable Initialization Subroutine
RCSPRM	SM RCS Propellant Remaining Module

NOMENCLATURE (Continued)

REV	Revolution
SI	Solar inertial
SM RCS	Service Module Reaction Control System
SODB	Skylab Operational Data Book
TACS	Thruster Attitude Control System
TACIMP	TACS impulse usage in attitude hold mode
TACSPRS	Total TACS Impulse and SM RCS Propellant Remaining Subroutine
TM	Maneuver time
TOAHS	TACS Only Attitude Hold Subroutine
TOMS	TACS Only Maneuvering Subroutine
TTICM	Total TACS Impulse Consumed Module
UIO	User input options
VDM	Venting Disturbance Module

NOMENCLATURE

$A_1, A_2, A_3, \ldots A_{N+1}; A_{11}, A_{22}, A_{33}$	Program constants
B11,B22,B33	Program constants
β	Beta angle-angle between orbit plane and earth-sun line at orbit noon
C_1, C_2, C_3, C_4, C_6; C11,C22,C33; C_X, C_Y, C_Z	Program constants
CONFIG	Input option flag
D1, D2,; D11	Program constants
D	Disturbing torques acting on vehicle
DC	SM RCS jet duty cycle for maneuvers
db_x, db_y, db_z	Input values for SM RCS phase plane deadbands
$DTIMP_X$, $DTIMP_Y$, $DTIMP_Z$	TACS impulse usage for nulling disturbance torques
E1, E2, E3, E4, E5	Program constants
EIMPC	Event impulse consumed
EIMPT	Total impulse to be debited
ε_X, ε_Y, ε_Z	Event maneuver angles
F	SM RCS thrust
FC	SM RCS event fuel consumption
Fuel RM	SM RCS fuel remaining
GG_X, GG_Y, GG_Z	Gravity gradient disturbance torques in X, Y, and Z body axes
GSMRCX, GSMRCY, GSMRCZ	TACS impulse usage for nulling gravity gradient torques in SM RCS control mode
H	Altitude of orbit above the earth
HMAX	Maximum allowable CMG angular momentum
HX, HY, HZ	Input maneuver angular momenta in body axes

HXTO, HYTO, HZTO	Total CMG angular momentum accumulation in X, Y, and Z axes
H_{XX}, H_{YY}, H_{ZZ}	CMG angular momentum accumulation in X, Y, and Z axes in attitude hold mode
HACX, HACY, HACZ	CMG angular momentum accumulation during a SI or LV maneuver
H_X, H_Y, H_Z	Change in vehicle angular momentum for one attitude hold cycle
IATT	Input option flag
ICAGE	Input option flag
IMPC	Total TACS impulse consumed
I_{MIB}	Specific impulse of minimum impulse firing
IPAR	Input option flag
I_T	Minimum impulse bit for RCS thruster
I_{PX}, I_{PY}, I_{PZ}	Moments of inertia in CSM coordinates
I_{PXY}, I_{PXZ}, I_{PYZ}	Products of inertia in CSM coordinates
I_{XY}, I_{YZ}, I_{XZ}	Product of inertia in OA coordinates
I_X,I_Y,I_Z; I_{XX}, I_{YY}, I_{ZZ}	Moments of inertia in OA coordinates
J	Body axes moments of inertia, I_{XX},I_{YY},I_{ZZ}
K_X,K_Y,K_Z; K_{11}, K_1, K_2, K_6	Program constants
L	Moment arms; L_X, L_Y, L_Z
L_X, L_Y, L_Z	Moment arms in X,Y, and Z OA coordinates
MNVR	Input option flag
MR	Mixture ratio
NBAR	Orbit period
NTM	Dump midnight
NU, NJ	Number of TACS or SM RCS jets controlling per control axis

OC	Oxidizer consumed for CSM event
PC	Total SM RCS propellant consumption
PER	Percentage of HMAX for determining CMG saturation
PP	SM RCS propellnat usage for pitch maneuvers
PR	SM RCS propellant usage for roll maneuvers
PSIA	Pounds per square inch absolute
PT	SM RCS propellant usage for translations
PY	SM RCS propellant usage for yaw maneuvers
PQA	Pitch and yaw moment arms for CSM computations
P_X, P_Y, P_Z	Time to complete one limit cycle of attitude hold about X, Y, and Z axes
QA, QB, QC, QD	SM RCS quad propellant consumption
QN	Quantity of gaseous nitrogen remaining for TACS
Q	Intermediate variable in MAMRM computations
R	Pitch and yaw moment arm for CSM
RA	Roll moment arm for CSM
RE	Radius of earth
RSIVB	Radius of the vehicle
RM	Roll moment for CSM
SILV	Input option flag
SMRCSX, SMRCSY, SMRCSZ	Total SM RCS propellant consumption for control about X, Y, and Z axes
ST	Application of pitch and yaw force for CSM
STR	Application of roll force for CSM
TATH	TACS thrust
$TAHIMP_X$, $TAHIMP_Y$, $TAHIMP_Z$	TACS impulse usage for attitude hold about X, Y, and Z axes

TCP	TACS chamber pressure
tesr, tess	Time of estimated orbital sunrise and sunset
t_f	Time of event termination
T1, T2	Intermediate variables in computations of gravity gradient disturbance torques
TISP	TACS specific impulse consumed
$TMIMP_X$, $TMIMP_Y$, $TMIMP_Z$	TACS impulse usage for a maneuver about X, Y, and Z axes
TM1	Torque produced by SM RCS firings about Y and Z axes
t_{mp}	Maneuver time for eigenaxis maneuver
TM	Total maneuver time for SI or LV maneuver
TN	Time of orbit noon
TOTUSEP	Total usables SM RCS propellant remaining
TOTALPR	Total SM RCS propellant remaining
to, ts	Time of event initialization
TP	TACS pressure
t_r	Time required to achieve orbital rate
TSP	TACS sphere pressure
t_w	Time duration of ramp portion of SI or LV maneuver
ΔT	TACS minimum impulse bit
Δt_A	Time duration of attitude hold
ΔT_1	SM RCS minimum impulse bit
VSMRCX, VSMRCY, VSMRCZ	SM RCS propellant consumption due to venting torques about CSM X, Y,and Z axes axes
VTIMPX, VTIMPY, VTIMPZ	TACS impulse consumption due to venting torques about OA X, Y, and Z axes
VTX, VTY, VTZ	Venting disturbance torques about X, Y, and Z axes

V_Z, V_Z	Angle of rotation required about Z axis to put X principal axis in orbit plane
ΔV	Velocity to be gained for +X translations
W, W_P	SM RCS propellant consumption
W_X, W_Y, W_Z	SM RCS propellnat consumption for attitude hold about X, Y, and Z axes
$\dot{W}$	SM RCS propellant consumption rate
WV	Vehicle weight
XC, YC, ZC	CSM control axes
X_V, Y_V, Z_V; X_{OA}, Y_{OA}, Z_{OA}	Vehicle control axes
X1, X2	Program constants
XI	Orbital inclination angle
Y1, Y2	Y axis offset moment arms
Z1, Z2	Z axis offset moment arms
$ZTIMP_X$, $ZTIMP_Y$, $ZTIMP_Z$	TACS impulse usage for zeroing CMG's about X, Y, and Z axes
θ, θ_P	Vehicle position with respect to orbit noon
$\theta_{dbx}, \theta_{dby}, \theta_{dbz}$	TACS or I.U. phase plane angular dead-bands in X,Y, or Z axes
$\dot{\theta}_{dbx}$, $\dot{\theta}_{dby}$, $\dot{\theta}_{dbz}$	TACS or I.U. phase plane rate deadbands in X, Y, or Z axes
θ_f	Orbit position at event termination
θ_o	Orbit position at event initialization
$\ddot{\theta}_L$	Limiting acceleration for maneuvers
θ_{esr}, θ_{ess}	Orbit position for the estimated sunrise and sunset
θ_R	Eigenaxis maneuver angle
θ_X, θ_Y, θ_Z	Maneuver angles about X, Y, or Z OA axes
$\dot{\theta}_X, \dot{\theta}_Y, \dot{\theta}_Z$	Maneuver rates about X, Y, or Z axes
$\emptyset$	Misalignment between OA and CSM control axes

NOMENCLATURE (continued)

α	Roll cant angle
Ω_o, OMEGO1	Orbital rate

1.0 INTRODUCTION

The Thruster Attitude Control System (TACS) and Service Module Reaction Control System (SM RCS) Consumables Program generates consumables budgets for the TACS and SM RCS in response to an input mission event description. The program may be used as an aid to preflight mission planning, contingency analyses, and backup SM RCS studies.

The program uses previously supplied parametric data from detailed simulations to determine TACS or SM RCS consumption for maneuvers and attitude hold. As such, the program is basically a bookkeeping program and is not an actual simulation of vehicle or hardware performance. The parametric data is stored in the program in the form of polynomial equations with tabularized coefficients which can be easily updated as required. For events not within the range of the stored parametric data, the capability is also included to compute consumables information using theoretical equations.

TACS or SM RCS consumption for an event is determined as a function of vehicle mass properties, vehicle trajectory (orbit position, beta angle orbital rate), disturbance torques, control system, TACS or SM RCS minimum impulse bit, and event characteristics. The vehicle mass properties are specified by input event data or by Skylab Operational Data Book values which are stored in tabular form in the program. The trajectory data for processing each event is computed within the program or input separately as event data or via a tape. After the trajectory information and vehicle mass properties are determined for an event, the TACS or SM RCS consumables requirements are computed using parametric data and/or theoretical equations. The consumables requirements which are computed by the program for an event include the effects of external disturbance torques where practical.

A general flow chart containing a brief description of the function of each subroutine in the TACS-SM RCS Consumables Program is given in Figure 1. Table 1 lists the pertinent equations associated with each major subroutine and module of the program.

2.0 PROGRAM DESCRIPTION

The types of events which can be processed by the TACS-SM RCS Consumables Program are tabulated in Table 2 in terms of the event category, type, and class. Three of the event categories define the control system to be used for performing an event. The fourth category, special events, allows the user to debit fixed quantities of TACS or SM RCS consumables and to initialize the program at an arbitrary point in the Skylab mission. The event categories are further divided into event types and classes. The types classify the event as either attitude hold, maneuvers, or SM RCS translations. The different classes define the characteristics of the event and specify the necessary input data required to process the event.

The events to be performed during the Skylab mission are specified by an input event timeline which details the type of maneuver, the control mode, and the maneuver characteristics. The TACS or SM RCS consumables requirements for these events are represented in the TACS-SM RCS Consumables Program by either theoretical equations or equations which were derived from the results of detailed simulations. These equations include the effects of vehicle trajectory, vehicle mass properties, and external disturbance torques on TACS and SM RCS consumables usage.

The program has the capability of modelling the three control modes of TACS Only, CMG/TACS nested, and SM RCS. In the TACS Only control mode, attitude control can be simulated with either the I.U. or the ATMDC in control. Given an initial CMG momentum status, the program can compute the TACS impulse required to cage the CMG's to a zero momentum status and perform an attitude maneuver or attitude hold in either the solar inertial or local vertical attitude. The impulse required for nulling or adding a desired vehicle rate or the TACS impulse required to add or subtract a given amount of angular momentum in any axis can be computed.

The CMG/TACS nested control option is primarily designed to compute the TACS assist required for ERE and also has the capability to model an ERE pass with one CMG failed. CMG momentum status modelling is limited to a simplified approximation in that onboard control logic is not simulated. Momentum in the body axes is computed by integrating external torques on the body and assuming that the resultant momentum is stored in the CMG's. No attempt is made to account for momentum management among the CMG's. Since momentum dumping is not modelled, the momentum status must be initialized by assuming a specified status at the end of the scheduled dump period.

The SM RCS control modelling capability refers to CSM control of the cluster which is planned only as a backup method of control. The following situations can be modelled: attitude hold in solar inertial or local vertical, angular orientation maneuvers, translation maneuvers, and caging of the CMG's prior to maneuvering or for a backup CMG momentum dump.

A general flow diagram for the program is shown in Figure 1. Vehicle trajectory data and mass property data for an event are determined in the Parametric Variable Initialization Subroutine (PVIS). The Ground Elapsed Time (GET) is input with each event, and the Beta Angle and Orbit Position Module of the PVIS uses the GET to compute the vehicle orbit position, beta angle, orbit rate, and lighting conditions for each event. The Mass Properties Module (MPM) of the subroutine has values for the mass properties of the primary Skylab configurations stored in tabular form. The user selects the appropriate mass properties for an event by configuration flags. The MPM also computes the applicable jet moment arms for the event and transforms the mass properties into CSM coordinates if the CSM is controlling the vehicle. The Maneuver Angle and Maneuver Rate Module of the PVIS computes the body axes rotational rates for events involving eigenaxis maneuvers.

After the vehicle mass properties and trajectory data are determined for an event, the program calls one of five subroutines to compute the consumables requirements. Each subroutine has the capability to use either parametric data or theoretical equations to compute the TACS or SM RCS usage.

If parametric data is used in a subroutine to determine the TACS or SM RCS consumption for an event, the effects of gravity gradient and aerodynamic torques are included in the final results without additional computations. If theoretical equations are used, the effects of aerodynamic torques are not included, and the usage due to gravity gradient torques is computed in the Gravity Gradient Disturbance Module. With either approach, the effects of venting disturbance torques on consumables usage for an event are computed in the Venting Disturbance Module. The total TACS or SM RCS consumables usage for an event is determined by summing the usage required to null the venting disturbance torques with the usage required to perform the attitude hold, maneuver, or translation.

The total TACS or SM RCS usage for an event is used in the Total TACS Impulse Consumed and SM RCS Propellant Remaining subroutine to determine the current status of the consumables. The TACS or SM RCS usage for the event is then summarized and included in a tabular report on the current status of the TACS and SM RCS consumables. Samples of the program output format for each type of event are shown in Appendix A.

2.1 TACS IMPULSE CONSUMPTION LOGIC

The TACS consumption logic of the TACS-SM RCS Consumables Program can best be illustrated by a brief description of the TACS. The TACS consists of a cold gas blowdown (non-regulated) propulsion system which uses gaseous nitrogen to provide thrust for performing maneuvers and spacecraft stabilization. The gaseous nitrogen is stored in 22 spheres which are connected by a common manifold to supply each of the six TACS engines. The engines are grouped in two clusters with three engines per cluster as shown in Figure 2. Table 3 shows the rate direction produced by each jet for the coordinate system used in the program. This table shows that the X and Z axes are strongly coupled because any firing for control about one of these axes will produce a rate about the other axis. As each jet is fired, the change in pressure of the gaseous nitrogen in the supply spheres results in a lower thrust and a higher specific impulse for any subsequent firings.

The initial gaseous nitrogen pressure is expected to provide a thrust of approximately 100 lbs through each of the TACS jets. However, as the nitrogen gas is consumed, the nitrogen pressure and temperature vary and cause variations in the TACS performance (thrust, I_{SP}) throughout the mission. Presently, the program only determines the current TACS thrust as a function of the total TACS impulse consumed and does not include the effects of variations in temperature and pressure in computing TACS impulse requirements for an event.

The program computes the TACS impulse consumed for an event and uses this to compute the thrust and specific impulse available for a succeeding event. The methods used for computing the TACS impulse usage for events involving the TACS Only control mode are discussed in the following paragraphs.

2.1.1 TACS Only Attitude Hold

The TACS-SM RCS Consumables Program computes the TACS impulse requirements for spacecraft stabilization for either the solar inertial (SI) or local vertical (LV) attitudes(event type 1, classes 1 and 2). A representation of the SI and LV attitudes is given in Figure 3. The attitude hold events are used to maintain, within certain angular limits, a constant attitude for specified periods of time. The Apollo Telescope Mount Digital Computer (ATMDC) or the SIV-B Instrument Unit (I.U.) is used to control the vehicle during these periods of TACS Only attitude hold. The uncoupled phase plane diagram for either the I.U. or ATM control is shown in Figure 4. The angular and rotational rate limits (deadbands) for both the ATMDC and I.U. phase plane are shown in Table 4.

The input data required for processing TACS Only attitude hold events are shown in Table 2. Using this data, the necessary vehicle trajectory and mass property data for the event is determined in the PVIS. The TACS Only Attitude Hold subroutine (TOAHS) is then called and if the parametric approach has been selected, equations which have been derived from detailed simulations are used to compute the TACS usage. An example of this parametric data for the SI attitude is shown in Figure 5. This data includes the effects of gravity gradient and aerodynamic torques on TACS impulse usage in the attitude hold mode. The equations which were used to curve fit the data are of the form

$$\text{TACS impulse consumed} = A_1(\beta^N \Delta T^N) + A_2(\beta^{N-1} \Delta T^{N-1}) + A_3(\beta^{N-2} \Delta T^{N-2}) + \ldots A_{N+1} \qquad (1)$$

where A_1, A_2, A_3, A_{N+1} = constants

β = beta angle

ΔT = minimum impulse bit

If the phase plane deadbands or vehicle inertias for an event do not fall within the range of the parametric data, theoretical equations may be used to compute the TACS impulse usage. With this approach, the total change in angular momentum about the vehicle body axes due to gravity gradient torques is computed and the TACS impulse required to produce this change is estimated. This TACS impulse usage is then summed with the theoretical limit cycle TACS impulse requirements.

The theoretical limit cycle TACS usage is computed in the TOAHS using the equation

$$TAHIMP_{X,Y,Z} = \frac{\Delta H_{X,Y,Z}}{L_{X,Y,Z}} * \frac{\Delta t_A}{P_{X,Y,Z}} \qquad (2)$$

where $\Delta H_{X,Y,Z}$ = change in angular momentum for one attitude hold cycle about X, Y, or Z axis

$L_{X,Y,Z}$ = TACS jet moment arm in X, Y, or Z axis

Δt_A = duration of attitude hold

$P_{X,Y,Z}$ = time duration for one limit cycle in X,Y, or Z axis

The equations for $\Delta H_{X,Y,Z}$, $L_{X,Y,Z}$, and $P_{X,Y,Z}$ are listed in Table 1.

The TACS impulse required to null the gravity gradient torques is computed in the Gravity Gradient Desaturation Module. The equation used is of the form

$$DTIMP_{X,Y,Z} = C_{X,Y,Z} \int_{t_o}^{t_f} \frac{|D_{X,Y,Z}|}{L_{X,Y,Z}} dt + K_{X,Y,Z} \qquad (3)$$

where

$D_{X,Y,Z}$ = disturbing torque about either the X,Y, or Z axis

t_o = start time of the event

t_f = event termination

$L_{X,Y,Z}$ = TACS moment arm in either the X, Y, or Z axis

$C_{X,Y,Z}$, $K_{X,Y,Z}$ = constants for X, Y, or Z axis

The TACS impulse required to absorb the venting torques during an event is computed by the program for either the parametric or theoretical approach. These computations are performed in the Venting Disturbance Module which determines the TACS requirements for venting using an equation of the form

$$VTIMP_{X,Y,Z} = \int_{t_o}^{t_f} \frac{|VT_{X,Y,Z}|}{L_{X,Y,Z}} dt \qquad (4)$$

where

t_o, t_f = start time, final time

$L_{X,Y,Z}$ = jet moment arm for X,Y,or Z axis

$VT_{X,Y,Z}$ = venting torque in X, Y,or Z axis

The TACS impulse for nulling the venting torques is summed with the TACS impulse required to maintain attitude hold to yield the total consumable usage for the event. This result is used in the TACS Impulse Consumed module for determining the current TACS thrust, pressure, and specific impulse for the next event.

2.1.2 TACS Only Maneuvers

The TACS-SM RCS Consumables Program is capable of computing TACS impulse consumption for maneuvers with either the ATMDC or I.U. controlling the vehicle (type 2 events). The computations for determining TACS usage for maneuvers are performed in the TACS Only Maneuvering subroutine (TOMS). Maneuvers from the SI-to-LV or LV-to-SI attitude (class 4) are performed as single eigenaxis maneuvers during orbits in which ERE have been scheduled. Maneuvers commanded in the TACS Only Attitude Hold mode are also performed about an eigenaxis (class 3). The computations for transforming the eigenaxis rate into body axis rates are accomplished in the Maneuver Angle and Maneuver Rate Module (Paragraph 2.5.3). The resulting body axis rates are used in the TOMS to estimate the TACS impulse required for the eigenaxis maneuver. A typical maneuver profile for SI-to-LV maneuver is shown in Figure 6.

The rotational rates for eigenaxis maneuvers (classes 3 and 4) are computed within the program. For other than eigenaxis maneuvers, user inputs of either vehicle maneuver rates (classes 1 and 5), maneuver angles and maneuver duration (class 2), or body axes maneuver angular momenta (class 6) are required for the computation of the TACS impulse usage. Class 1 and class 5 events differ in that class 1 events estimate the TACS impulse required to initiate and terminate a rotational rate, while class 5 events estimate the impulse required to start or stop a rate.

The TACS impulse required to perform a maneuver is a function of the rotational rate, vehicle trajectory, vehicle mass properties, and the disturbance torques acting on the vehicle. The form of the theoretical equation used in the TOMS for computing the TACS impulse for a maneuver is

$$TMIMP_{X,Y,Z} = \frac{C_{X,Y,Z}\ I_{X,Y,Z}\ \dot{\theta}_{X,Y,Z}}{L_{X,Y,Z}} + K_{X,Y,Z} \qquad (5)$$

where

$C_X, C_Y, C_Z, K_X, K_Y, K_Z$ = constants for X, Y, and Z axes

$\dot{\theta}_X, \dot{\theta}_Y, \dot{\theta}_Z$ = rotational maneuver rates about X, Y, and Z axes

I_X, I_Y, I_Z = moments of inertia about X, Y, and Z axes

L_X, L_Y, L_Z = TACS jet moment arm

After the TACS impulse usage for maneuvers is computed, the TACS impulse required to maintain attitude hold during the maneuver is estimated in the TOAHS. The results from the TOMS and TOAHS are summed to provide the total event TACS impulse usage.

The effects of external disturbance torques are not included in the theoretical calculations of the TACS impulse usage for maneuvers because of the increased program complexity and computer processing time requirements. The effects of disturbance torques will be included by using parametric curves to determine the TACS usage or by changing the coefficients and constants of the theoretical equations so that the computed usage agrees with the results of the detailed simulations. This will be accomplished as simulation data becomes available.

2.2 SM RCS PROPELLANT CONSUMPTION LOGIC

The Service Module Reaction Control System (SM RCS) has sixteen (16) regulated 102.8 pound (nominal) thrusters which are grouped in clusters of four. The individual clusters are commonly referred to as Quads A, B, C, and D, and associated with each quad is a separate fuel and oxidizer supply with helium pressurization. The locations of the SM RCS quads with respect to the OA and CSM control axes are shown in Figure 7. The thrust axes for the SM RCS quads are rotated by an angle, Ø, about the X control axis of the TACS, and Figure 8 shows the relationship between the two coordinates.

The SM RCS will be used on the Skylab mission to perform backup and contingency cluster rotations, stabilization,and +X-translations. The SM RCS propellant usage for these events is computed in the program using theoretical equations. The parametric approach cannot be used because data from simulations is not presently available for development of the parametric data base. As data becomes available, the program can be changed to utilize the parametric data with minimum effort since the logic for this approach has been included in the program. The theoretical computations for SM RCS events have been simplified in order to reduce the complexity and processing time of the program. The onboard control logic for the CSM DAP is not included in the program and only the RCS usage for the YZ force control mode can be estimated. Table 5 presents the jets used for control in this mode.

The SM RCS propellant consumption for maneuvers and periods of attitude hold is computed on a single control axis basis. This is not consistent with the onboard CSM DAP logic which selects jets in such a manner as to minimize the number of jet firings in reducing vehicle attitude errors. However, in the majority of the cases the errors resulting in the computation of SM RCS propellant usage on a single axis control basis are negligible.

The SM RCS propellant consumption computations are performed with respect to the OA control axes for events involving maneuvers, and the effects of the misalignment between the CSM and OA control axes are included in the results. For attitude hold events, the computations are performed with respect to the CSM coordinate system. The SM RCS propellant required to null the roll rates introduced as a result of the Z_{cg} offset is included in both the maneuver and attitude hold computations.

While the program uses a minimum on-time of 15 msec for each SM RCS jet firing, the capability to compute the usage for other firing times is available. Curves from the SODB relating minimum impulse bit, specific impulse, and mixture ratio have been included in the program as a function of the minimum on-time for each jet. These equations have the form

$$\text{OUTPUT} = A_{11}(\text{EOT})^2 + A_{22}(\text{EOT}) + A_{33} \tag{6}$$

where

$$\begin{aligned} \text{OUTPUT} &= \text{desired variable} \\ A_{11}, A_{22}, A_{33} &= \text{constants} \\ \text{EOT} &= \text{minimum firing time.} \end{aligned}$$

The computed SM RCS propellant consumption for each event is divided between the quads in proportion to the center of gravity offset. Mixture ratios of 2.0 for maneuvers and 1.63 for attitude hold are used in the SM RCS Propellant Remaining Subroutine to determine the total SM RCS fuel and total propellant remaining.

The following paragraphs present additional information concerning the computations of the SM RCS usage for attitude hold, maneuvers, and +X translations.

2.2.1 SM RCS Attitude Hold

The TACS-SM RCS Consumables Program is capable of computing the RCS usage requirements for spacecraft stabilization in either the SI or LV mode (type 4, class 1 event). A description of the SI and LV attitudes is given in Figure 3. The SM RCS Attitude Hold Subroutine is used to compute the RCS usage for maintaining these attitudes. This subroutine assumes that jets 3,4,7, and 8 (-X thrusters) are inhibited in the docked configuration and that only YZ Force Control mode is used to maintain attitude.

Attitude hold propellant consumption rate is computed as a function of cluster inertia, number of jets firing, specific impulse, minimum impulse per firing, and the disturbing torque acting on the vehicle. The theoretical propellant consumption for a limit cycle period of Δt_A seconds is given by the equation having the form of

$$W = \frac{K_1 (NJ)^2 \Delta t_A + C_1}{I} \quad ; \quad K_1 = \frac{C_2 \Delta T_1^2 L \, 57.3}{4 \, I_{SPCSM} \, \theta_{db}} \tag{7}$$

where

NJ = number of jets firing
I = vehicle moment of inertia in CSM coordinates
C_2 = constant determined by moment arms and products of inertia
ΔT_1 = minimum impulse per firing
L = moment arm
θ_{db} = phase plane angular deadband in degrees
K_1 and C_1 = curve-fitting constants
I_{SPCSM} = SM RCS specific impulse

The effects of gravity gradient torques on SM RCS usage are computed in the Gravity Gradient Disturbance Torque Module. The equation used to compute the usage is of the form

$$W_{X,Y,Z} = \int_{t_o}^{t_f} \frac{|GG_{X,Y,Z}|}{L_{X,Y,Z}(I_{SPCSM})} \, dt \tag{8}$$

where

$GG_{X,Y,Z}$ = gravity gradient torques in CSM coordinates

$L_{X,Y,Z}$ = moment arms

t_o = time of event initiation

t_f = time of event termination

The gravity gradient torques are transformed to CSM coordinates by the transformation matrix shown in Figure 8. An equation which has the same form as Equation (8) is also used to compute the RCS attitude hold usage due to venting disturbances. These computations are performed in the Venting Torque Disturbance Module.

The SM RCS usage due to attitude hold limit cycling and disturbing torques is summed to give the total propellant consumed for an event. The total usage per quad is then determined by dividing the total usage between the four propellant supply systems in proportion to the center of gravity offset.

The SM RCS consumption module of the TACS-SM RCS Consumption subroutine uses a constant mixture ratio of 1.63 to compute the total oxygen and fuel used for attitude hold events. The outage and the total usable propellant remaining is determined using a mixture ratio of 2.05. Other output quantities for a SM RCS attitude hold event consist of the average mixture ratio and the total propellant, oxygen, and fuel remaining.

2.2.2 SM RCS Maneuvers

The SM RCS propellant usage for maneuvering the cluster is a function of the maneuver rates, cluster mass properties, and disturbing torques acting on the vehicle. The computations for determining the SM RCS propellant consumption for maneuvers are performed in the SM RCS Maneuver and Translation subroutine. This subroutine uses theoretical equations to estimate the SM RCS usage for an event. These equations have constants which can easily be updated to incorporate the results of parametric data analyses. The subroutine has been simplified for budgeting purposes by only including single-axis maneuvers about the OA axes (type 5, classes 1, 2, 3). The RCS usage for 2 and 3 axis maneuvers is computed by summing the usage for the respective single axis maneuvers (type 5, classes 4 and 5).

The propellant consumption for a maneuver is computed using equations which have the form

$$W = K_{11} \left(\frac{2*I*RATE*\dot{W}}{TM1}\right) + K_{22} \qquad (9)$$

where

I = moment of inertia in OA coordinates

K_{11}, K_{22} = constants

RATE = maneuver rate in OA coordinates

TM1= total moment produced by jets

$\dot{W}$ = RCS flow rate

The misalignment of the CSM and OA control axes (Figure 8) makes it necessary to null rates introduced in the other axes to achieve a single axis maneuver in pitch or yaw. Also, the Z_{cg} offset requires that the SM RCS be toggled in order to prevent roll. This jet toggling is directly proportional to the moment arms resulting from the Z_{cg} location. The program compensates for the cross-coupling of rates and Z_{cg} offset by computing the total applied moment (TM1) as a function of the duty cycle of the nulling jets and the jet moment arms.

The effects of disturbance torques are not included in the theoretical calculation of SM RCS usage for maneuvers because of the increased program complexity and computer processing time requirements. The disturbance torques will be included by using parametric curves to determine the RCS usage or by changing the coefficients and constants of the theoretical equations to fit the results of simulations as data becomes available.

2.2.3 SM RCS Translations

The SM RCS propellant consumption for +X translations is computed in the SM RCS Maneuver and Translation subroutine. The translation section of this subroutine uses theoretical equations to compute the RCS usage for either four jet (type 5,class 6), or two jet (type 5, classes 7 and 8) +X translations.

The SM RCS usage for +X translations is computed using an equation of the form

$$W_T = \frac{K_6*WV*\Delta V}{G*I_{SP}*COS\alpha} + C_6 \qquad (10)$$

where

G = gravity constant (32.17 ft/sec^2)

I_{SP} = steady state specific impulse

α = roll cant angle

ΔV = velocity to be gained

K_6, C_6 = constants

WV = vehicle weight

During translations of the cluster, the SM RCS jets will be toggled in order to prevent rotations due to the center-of-gravity offset. Provisions have been made to account for the propellant requirements of each quad as a result of the toggling. The SM RCS requirements for nulling gravity gradient disturbing torques and maintaining attitude during the translation are not included in the results for +X translations.

2.3 NESTED CMG/TACS CONSUMPTION LOGIC

The Nested CMG/TACS control system consists of three CMG's, each having a momentum storage capability of 2300 ft-lb-sec. This storage capability is used to produce moments on the vehicle for attitude stabilization and maneuvering. During the Skylab mission, momentum management is performed in order to prevent the bias components of gravity gradient and other torques from saturating the CMG system and making it ineffective in controlling the vehicle. In the nested mode, the TACS will be used to keep the CMG's from reaching saturation and to assist the CMG's when the phase plane rate and attitude deadbands are exceeded.

The CMG/TACS nested control option of the TACS-SM RCS Consumables Program is primarily designed to compute the TACS assist required during ERE orbits to keep the CMG's from saturating. Since the program is not a detailed simulation of the CMG's or environment, the TACS impulse usage for assisting the CMG's to maintain attitude stabilization cannot be determined.

Two techniques are used in the consumables program for determining the TACS impulse requirements during an ERE orbit. One technique utilizes parametric data to determine the usage during the orbit. The other approach utilizes a combination of theoretical equations and parametric equations to estimate the TACS impulse requirements during the orbit. Presently, both of these techniques are in the development stage while data from detailed simulations are being requested and analyzed. This section of Volume I will be updated to include changes that may result when the program is finalized.

The following paragraphs will discuss the approach which uses a combination of theoretical equations and parametric data for determining the TACS impulse requirements during ERE orbits.

2.3.1 Nested CMG/TACS Attitude Hold

The TACS impulse requirements for assisting the CMG's in maintaining either the SI or LV attitude are computed in the Nested CMG/TACS subroutine. During an ERE orbit, periods of attitude hold in both the SI and LV attitudes will be required. At the start of the ERE orbit, the CMG momentum accumulation is initialized with a specific bias (usually zero) at the end of the scheduled dump period. This is necessary because the CMG's and momentum dump maneuvers are not modelled in the subroutine. The CMG momentum status in body axes is computed at another position in the orbit by integrating the external torques acting on the body and assuming that the resultant momentum is stored in the CMG's. The Gravity Gradient Disturbance Module computes the CMG momentum accumulation due to gravity gradient torques from the initial orbit position, θ_p, to the final orbit position, θ_f, which corresponds to the termination of the attitude hold period. The CMG momentum accumulation due to venting torques is computed in the Venting Disturbance Module and summed with the momentum accumulation due to gravity gradient torques. The total CMG angular momentum is then checked for violation of the prescribed level (96 percent) of the maximum allowable momentum (6900 ft-lb-sec). If the momentum accumulation is greater than the prescribed level, the TACS impulse required to reduce the CMG accumulation to a preset value is computed.

2.3.2 Nested CMG/TACS Maneuvers

The Nested CMG/TACS subroutine has the capability to estimate the TACS impulse requirements for assisting the CMG's in performing either SI-to-LV or LV-to-SI maneuvers during ERE orbits. Prior to one of these maneuvers, the attitude hold portion of the subroutine is used to establish the CMG status at the start of a maneuver (see Paragraph 2.3.1). The body axes maneuver rates for the eigenaxis maneuver are computed in the MAMRM, and these rates are used to determine the CMG momentum required for initiating the ramp portion of the maneuver profile (Figure 6). The total CMG angular momentum is computed and checked for violation of the saturation level. Parametric data is then used to estimte the CMG momentum buildup during the constant rate period of the maneuver (shaded area of Figure 6). The total CMG momentum accumulation is determined and checked for violation of the saturation level. Finally, the CMG angular momentum required to terminate the maneuver and achieve orbital rate for a SI-to-LV maneuver is determined.

The total CMG angular momentum accumulation is checked at five points during the maneuver (see Figure 6) for violation of the saturation level. If the total accumulation is greater than this level, the TACS impulse required to reduce the total angular momentum to a preset value is computed. The event TACS impulse consumption is used in the Total TACS Impulse Consumed Module to compute the current TACS thrust, I_{SP}, pressure, and quantity of gaseous nitrogen remaining.

2.4 TOTAL TACS IMPULSE CONSUMED AND SM RCS PROPELLANT REMAINING SUBROUTINE (TACSPRS) LOGIC

This subroutine determines the current status of the TACS and SM RCS consumables after each event. The TACS or SM RCS event requirements are computed by other subroutines of the TACS-SM RCS Consumables Program and are routed to the TACSPRS by the Driver. For TACS events, the TACSPRS utilizes parametric data of the SODB to compute the total impulse consumed, the quantity of gaseous nitrogen remaining, and the current TACS specific impulse, thrust, and pressure. If the event involves SM RCS control, the subroutine computes the total (usable) SM RCS propellant remaining per quad, the average mixture ratio, and propellant outage.

Presently, the status of TACS consumables is computed at an average orbit temperature of 10°F because data necessary to include the effects of varying temperatures are not available. However, logic has been included in the TACSPRS to allow determination of the TACS status as a function of temperature when the necessary data becomes available.

2.4.1 Total TACS Impulse Consumed Module (TTICM)

Data from the SODB has been modelled in the TTICM using polynomial equations of the form

$$V = A_{11}X^3 + A_{22}X^2 + A_{33}X + C. \qquad (11)$$

The coefficients of these equations were determined using a least-squares error curve-fitting technique.

When the TTICM is entered, the total TACS impulse consumption is determined by summing the event impulse usage with all the previous TACS impulse usage. The current TACS thrust is determined using the total impulse consumed and the equations for the curve of Figure 9. The TACS thrust is used to determine the current sphere and thruster chamber pressures from the equations for the curves of Figures 10 and 11. The average TACS specific impulse for the event is computed using Figure 12 and the values of total impulse consumed before and after the event. This average specific impulse is then used to determine the quantity of gaseous nitrogen consumed during the event.

2.4.2 SM RCS Propellant Remaining Module (RCSPRM)

The SM RCS propellant consumption for an event is determined on a per quad basis by the SM RCS Attitude Hold Subroutine or SM RCS Maneuver and Translation Subroutine. The total event RCS propellant consumption is then determined in the RCSPRM and separated into fuel and oxidizer consumption using the event mixture ratio. The mixture ratio for maneuver and attitude hold events are considered to be constants of 2.00 and 1.63, respectively. The total usable propellant remaining is calculated as the maximum mixture ratio of 2.05 multiplied by the total fuel remaining. Other SM RCS variables such as the average mixture ratio, propellant outage (total propellant remaining minus total usable propellant remaining), and total consumables remaining per quad are also computed.

2.5 PARAMETRIC VARIABLE INITIALIZATION SUBROUTINE (PVIS) LOGIC

The PVIS determines most of the input parameters required by other subroutines in the program for processing events. It consists of three modules: The Beta Angle and Orbit Position Module (BAOPM); the Maneuver Angle and Maneuver Rate Module (MAMRM); and the Mass Properties Module (MPM). These modules compute parameters such as orbit position with respect to orbit noon, beta angle, periods of orbit darkness, maneuver angles and rates, and vehicle mass properties. The PVIS can use either theoretical equations or tape inputs to determine the trajectory data for an event. This combination provides the flexibility and accuracy required for preparing preflight budgets.

The input data required by the PVIS consist of Mission Independent Data (MID), option flags, and event input timeline data. The MID are prestored in the program in tables and as constants for equations. The option flags determine if parameters normally computed in the subroutine are to be input directly with the event data or read from a premounted data tape.

The coordinate system used in the Parametric Variable Initialization Subroutine agrees with the Orbital Assembly (OA) axes of the Skylab Program Operational Data Book (SPODB). This system differs from the coordinate system of the Program Definition Document (PDD) by a 180° rotation about the +X OA axis. Also, the sign of the products of inertia from the SODB have been changed because the program uses a negative integral to define the products of inertia. The SODB defines the products of inertia with a positive integral.

The following paragraphs discuss the computations that are performed in each module.

2.5.1 Beta Angle and Orbit Position Module (BAOPM)

The Beta Angle and Orbit Position Module consists of three subroutines (POSTIN, INITIAL, ANGLE) which calculate the vehicle position with respect to orbit noon, the angle between the sun line and orbit plane at orbit noon (beta angle), the time of entering or leaving the orbital eclipse, and the earth central angle of the orbital eclipse. The parameters stored in the module can be updated by the user with the inputs for an event description. If no external updates are supplied, the module uses the stored data to calculate all of the parameters required for processing the event.

The Beta Angle and Orbit Position Module first determines the orbit orientation parameters at orbit insertion using the stored or input initialization constants (Table A-1). These parameters are used to find the initial values of orbit noon, beta angle, and the orbital eclipse half angle. Using the event ground elapsed time (GET), the module then accounts for the motion of the sun and ascending node as time advances from insertion to calculate the event rev number (number of times the vehicle passes the first orbit noon). It also calculates the orbit noon for the event rev, the beta angle at orbit noon, the time and orbit position of the orbital eclipse, and the vehicle orbit position at the GET specified.

2.5.2 Mass Properties Module (MPM)

The Mass Properties Module uses data from the Skylab Program Operational Data Book (SODB) to determine vehicle mass properties with respect to the OA coordinate system. The SODB information is prestored in tabular form as Mission Independent Data. A specific set of vehicle mass properties is selected from the table using configuration flags in the event data. If the vehicle mass properties are not specified in the event data and the configuration flag has not changed, the event is processed using the vehicle configuration of the previous event.

The MPM determines the vehicle mass properties with respect to the SODB(OA) coordinate system for all TACS events. The vehicle mass properties for CSM attitude hold events are determined with respect to the CSM coordinate system. The equations used for transforming the vehicle mass properties from OA to CSM coordinates and the pertinent equations for the Mass Properties Module are shown in Table 1.

All vehicle mass properties for TACS events are output with respect to the SODB coordinate system. The vehicle mass properties for CSM attitude hold events are output with respect to CSM coordinates. The output format of the mass properties for TACS and CSM events are shown in Appendix A.

2.5.3 Maneuver Angle and Maneuver Rate Module (MAMRM)

During a mission, all automatic solar inertial, local vertical, or attitude hold maneuvers will be performed about an eigenaxis. The Maneuver Angle and Maneuver Rate Module (MAMRM) determines the angle and rate of rotation about the eigenaxis and transforms the eigenaxis rate into rates about the vehicle body axes. These body axes rates are used in other subroutines of the TACS-SM RCS Consumables Program to compute the TACS impulse requirements for a maneuver. In addition to computing the body axis rates, the module also determines the maximum momentum required by the CMG's in performing the maneuver. This momentum is used in the Nested CMG/TACS Control Mode.

The techniques used in performing the local vertical,solar inertial,or attitude hold maneuvers are documented in the PDD (Reference 1). The proposed rate profile for Skylab SI maneuvers is shown in Figure 6. All eigenaxis maneuvers are initiated with a period of constant acceleration ($\ddot{\theta}_L$). Depending upon the specified maneuver time, a period of zero angular acceleration may be entered prior to the interval of constant deceleration. For maneuvers from the solar inertial to the local vertical attitude, orbital rate will be commanded about the vehicle Y axis after the eigenaxis maneuver is terminated. For local vertical to solar inertial maneuvers, orbital rate will be terminated prior to the eigenaxis maneuver. The pertinent equations used in this module are shown in Table 1.

2.6 GRAVITY GRADIENT AND VENTING DISTURBANCE MODULES

The Gravity Gradient and Venting Disturbance Modules compute the magnitude of the total change in angular momentum about the CSM or OA control axes due to gravity gradient or venting torques. The total change in angular momentum is used by each of these modules to compute the TACS impulse required to null the particular disturbing torque during periods of either SI or LV attitude hold.

The theoretical equations for the body axes gravity gradient torques in the SI or LV attitude are programmed in the Gravity Gradient Disturbance Module as a function of beta angle, orbit position, and V_Z. Theoretical equations have not been included in the Venting Disturbance Module since the venting torque profile must be input or stored as a function of time. The form of the equation used in both modules for determining the TACS impulse requirements for nulling the disturbance torque is

$$DTIMP_{X,Y,Z} = \int_{t_s}^{t_f} \frac{|D_{X,Y,Z}|}{L_{X,Y,Z}} \, dt \qquad (12)$$

where

$D_{X,Y,Z}$ = disturbing torque about X,Y, or Z axis

t_s = start time

t_f = event termination

$L_{X,Y,Z}$ = TACS moment arm in X,Y, or Z axis

The following paragraphs present more detailed descriptions of the logic of the Gravity Gradient Disturbance Module and Venting Disturbance Module.

2.6.1 Gravity Gradient Disturbance Module (GGDM)

This module computes the magnitude of the change in angular momentum about the vehicle body axes due to gravity gradient torques. Using this change in angular momentum, the TACS impulse required to null the gravity gradient disturbing torques is computed. The equation used is of the form of Equation (12)

In the solar inertial attitude, the gravity gradient torques in body axes are cyclic as shown in Figure 13 . In order to simplify the evaluation of the integral in Equation(12), the equations for determining the zero crossings of the gravity gradient torques are included in the module. Also, the equations for the integrals of the gravity gradient torques are included as a function of the initial and final orbit positions, beta angle, and V_Z. The beta angle and the angle V_Z are considered invariant for any particular orbit. Therefore, the integral in Equation(12)of the magnitude of the gravity gradient torques (or the total change in angular momentum due to gravity gradient torques) is only a function of the initial and final orbit positions.

Using the initial and final orbit positions for the period of SI attitude hold and the zero crossings of the gravity gradient torques, the magnitudes of the shaded areas in Figure 13 are computed. These areas are then summed to yield the total change in vehicle angular momentum due to gravity gradient torques in the SI attitude. This result is divided by the appropriate moment arm to compute the TACS impulse required to null the disturbance torques. In the local vertical attitude the gravity gradient torques are constant and the evaluation of Equation(12)is straightforward.

The subroutine also has the capability to compute the gravity gradient torques in the CSM control coordinates shown in Figure 8 . For the CSM events, the same logic as discussed above for the TACS events is followed. However, the gravity gradient torque equation and the equation representing the integral of the gravity gradient torques are transformed into CSM coordinates by the transformation matrix of Figure 8 . After the total change in angular momentum is computed the result is divided by the appropriate CSM RCS moment arms and minimum specific impulse, I_{SPCSM}, to obtain the CSM RCS propellant usage.

2.6.2 Venting Disturbance Module (VDM)

The capability to estimate the TACS impulse required to absorb venting torques has been included in the Venting Disturbance Module. The module consists of tabular data specifying the time and magnitude (or equation) of the venting torques about the X, Y, and Z body axes. This tabular data is scanned during an event to determine if venting torques are present. If torques are present, the additional TACS impulse requirements are estimated using Equation (12). In addition to the tabular data, an option flag is provided to the user which allows the venting torques to be input with the event data.

2.7 CMG ZEROING MODULE

The CMG Zeroing Module is used in the TACS-SM RCS Consumables Program for computing the TACS impulse required to cage the CMG's to zero momentum status. If the ICAGE flag is set to one by the user, this module is called by the TACS Only Attitude Hold subroutine, SM RCS Attitude Hold subroutine, or the SM RCS Maneuver and Translation subroutine. The module uses the current orbit position, θ_p, and the orbit position at the termination of the dump period, θ_o, to compute the CMG angular momentum accumulation due to gravity gradient torques. The equations for the angular momentum accumulation are modelled in the module as a function of the vehicle mass properties, beta angle, V_Z, and orbit position. These equations are shown in Table 1.

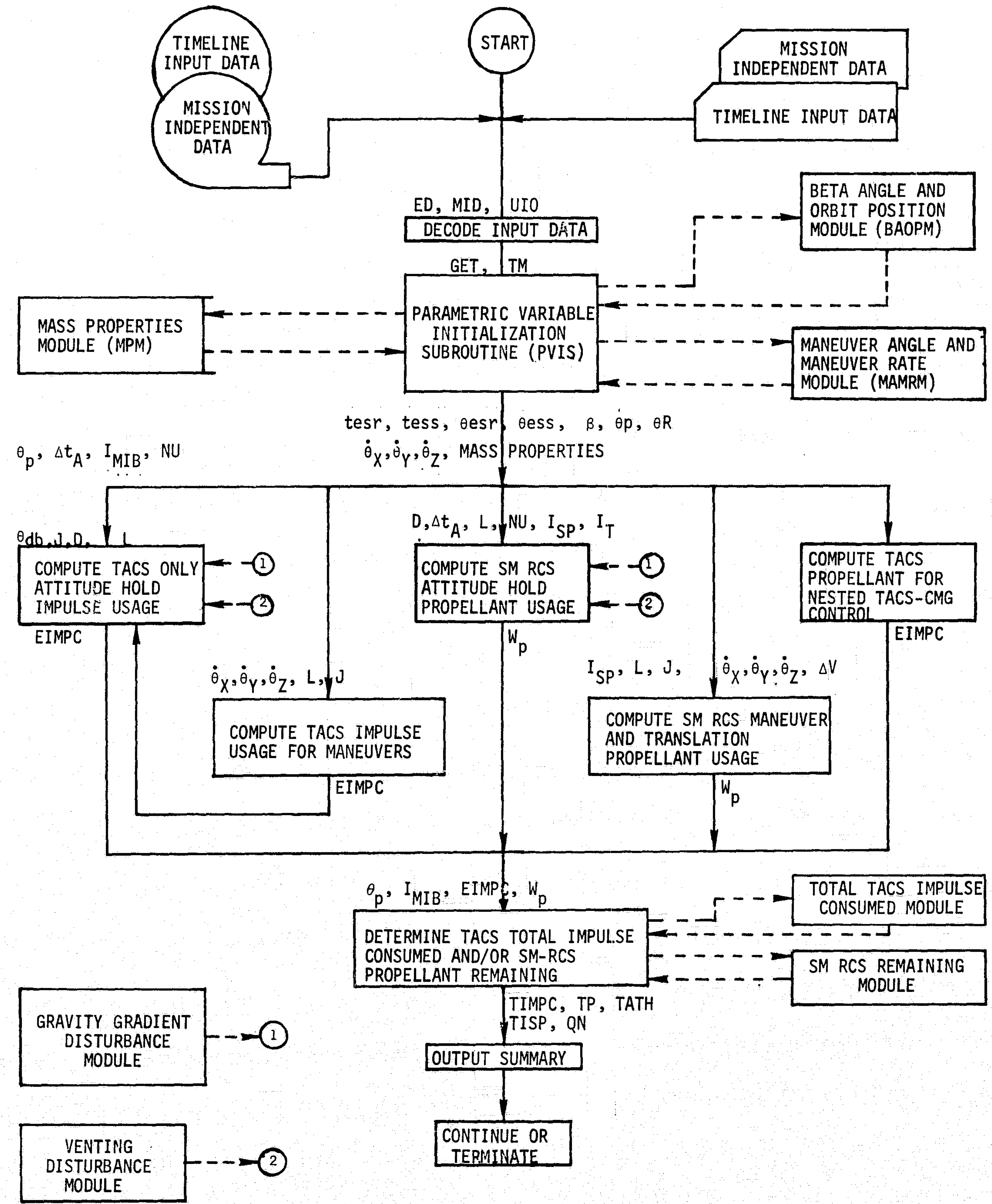


Figure 1 . General Flow Chart for TACS-SM RCS Consumables Program.

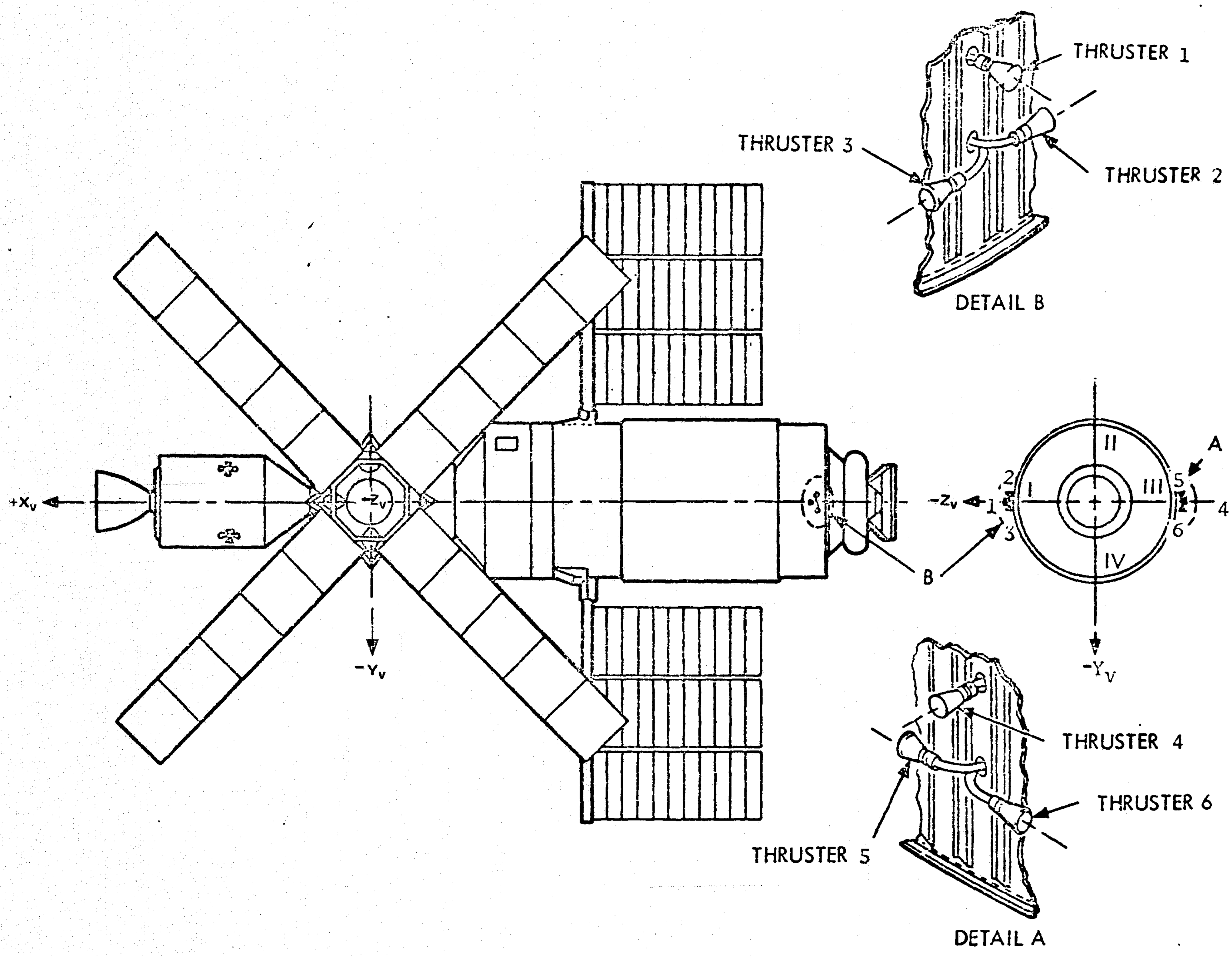


FIGURE 2. TACS Thruster Locations

NOTE: The X principal axis is in the orbit plane for the SI attitude (shown). For the local vertical attitude the $-Z_V$ axis is along the radius vector ($\beta=0$) and the X_V axis is in the orbit plane in the direction of the velocity vector.

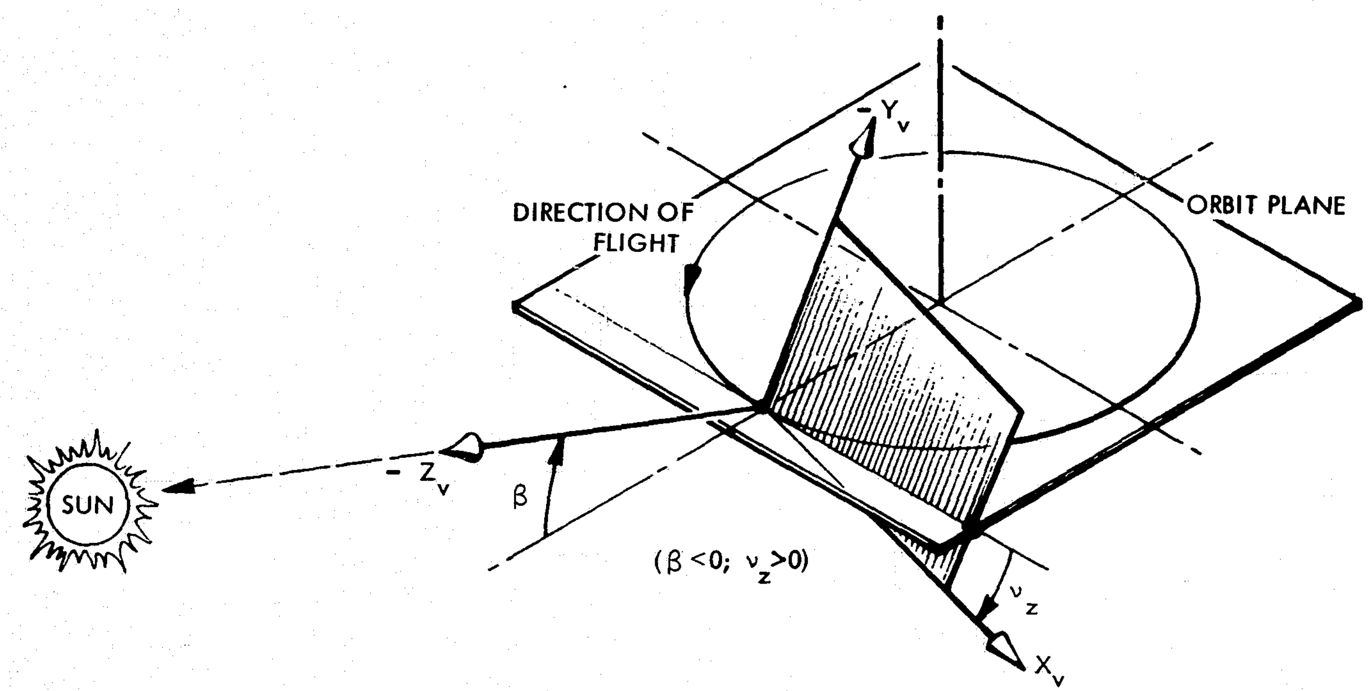


Figure 3. Definition of the solar inertial and local vertical attitude used in the TACS-SM RCS Consumables Program.

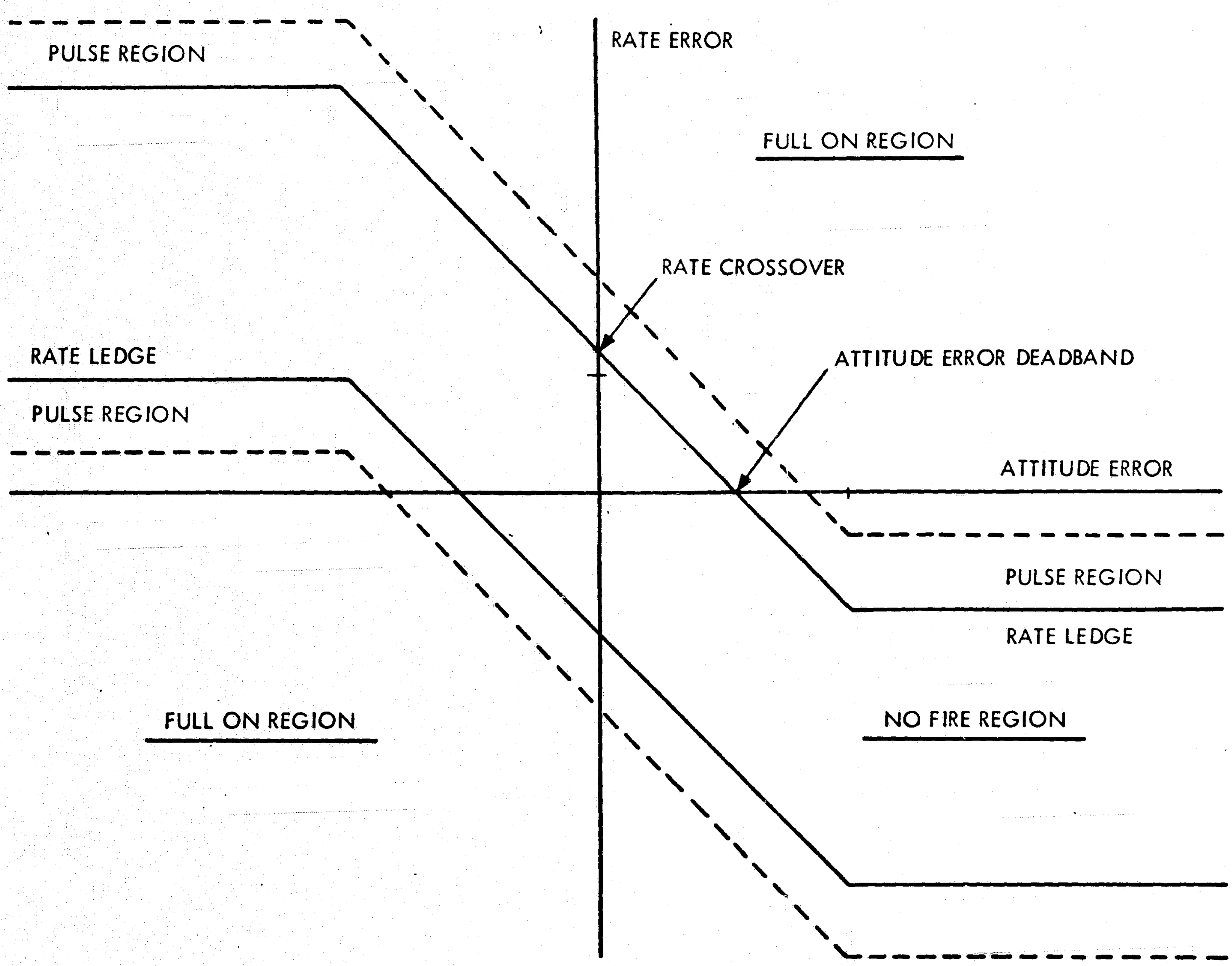


Figure 4 Uncoupled Phase Plane Diagram.

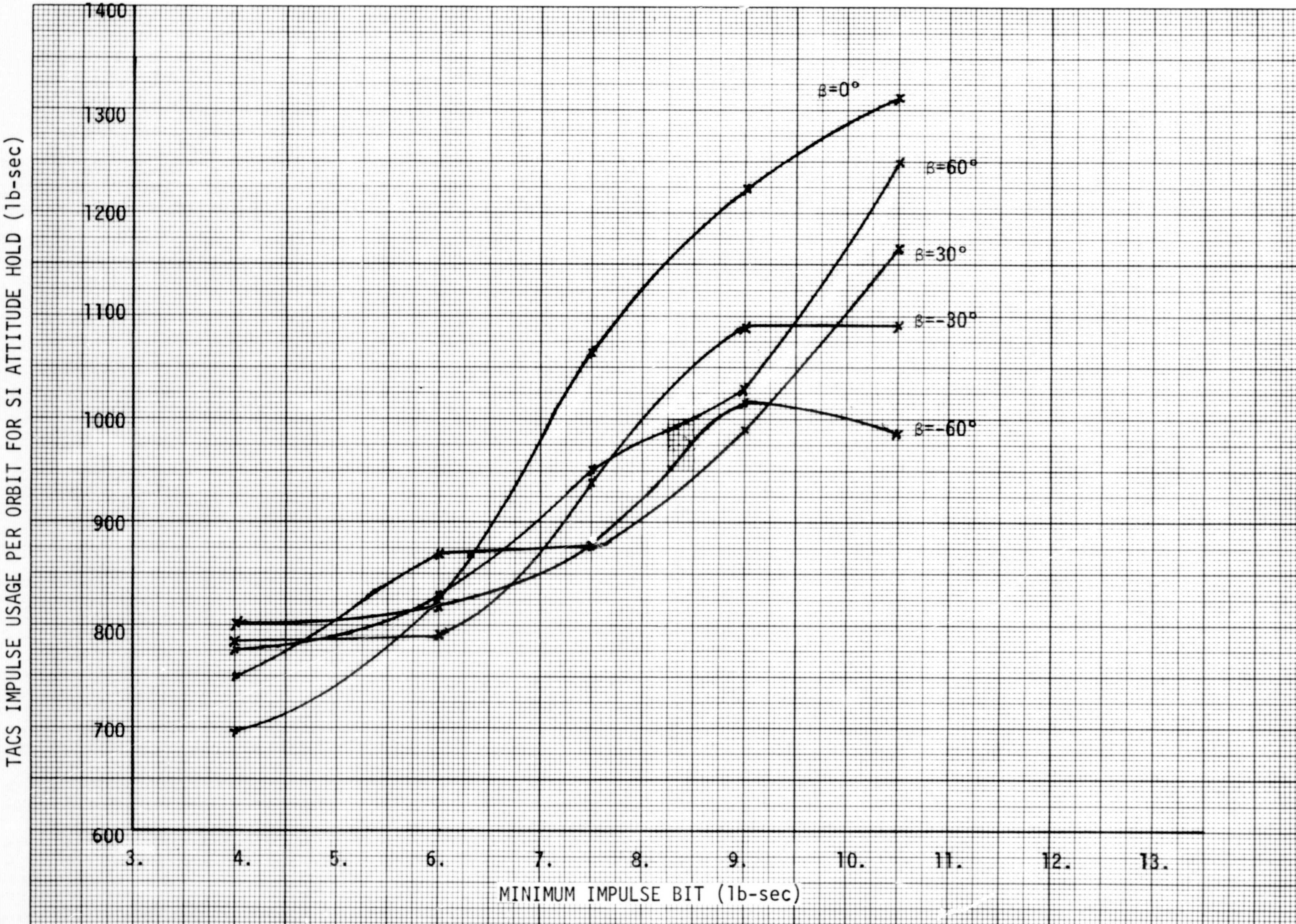
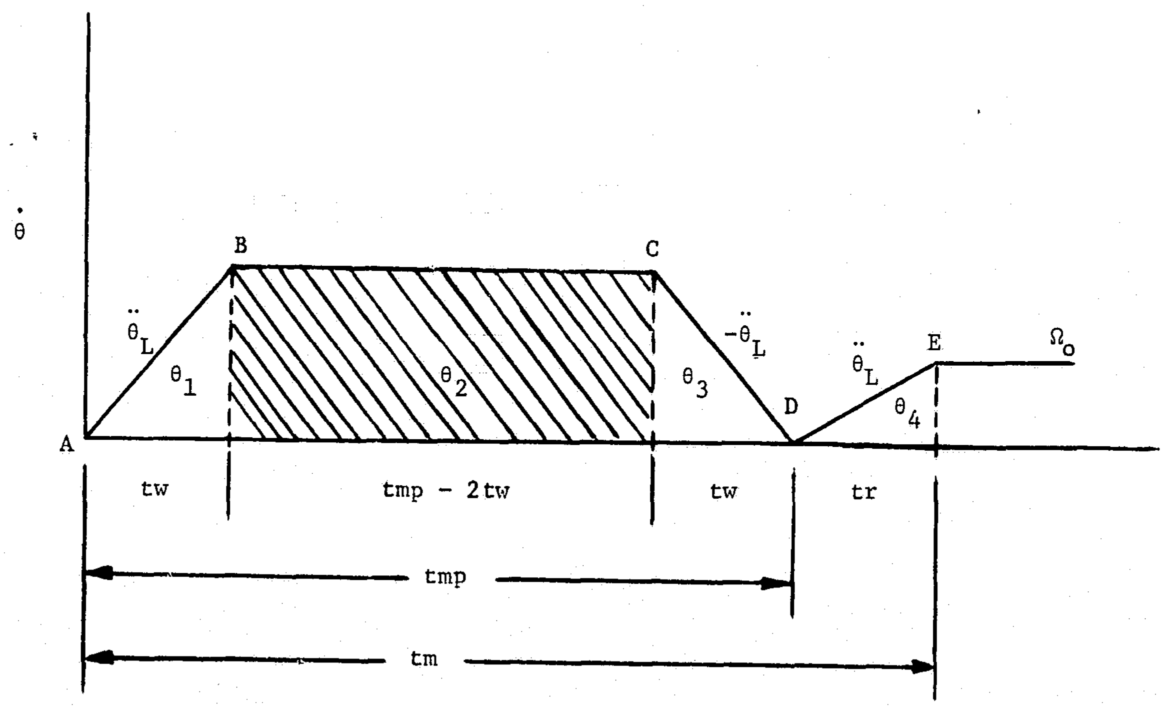


FIGURE 5. TOTAL TACS IMPULSE USAGE PER ORBIT FOR SOLAR INERTIAL (SI) ATTITUDE HOLD AS A FUNCTION OF BETA ANGLE AND MIB



1. $tw = \frac{tmp}{2} - \sqrt{\left(\frac{tmp}{2}\right)^2 - \frac{\theta_R}{\ddot{\theta}_L}}$

2. $Q = \left(\frac{tmp}{2}\right)^2 - \frac{\theta_R}{\ddot{\theta}_L}$

3. $tr = \frac{\Omega_o}{\ddot{\theta}_L}$

4. $tmp = tm - tr$

where tm is an input variable

$\ddot{\theta}_L$ is an acceleration constant

$\theta_R = \theta_1 + \theta_2 + \theta_3$ = computed eigenaxis maneuver

θ_4 is the pitch (y) axis maneuver to orbital rate (Ω)

A, B, C, D, and E are checkpoints for the Nested CMG/TACS Control Mode

FIGURE 6. SOLAR INERTIAL TO LOCAL VERTICAL MANEUVER PROFILE

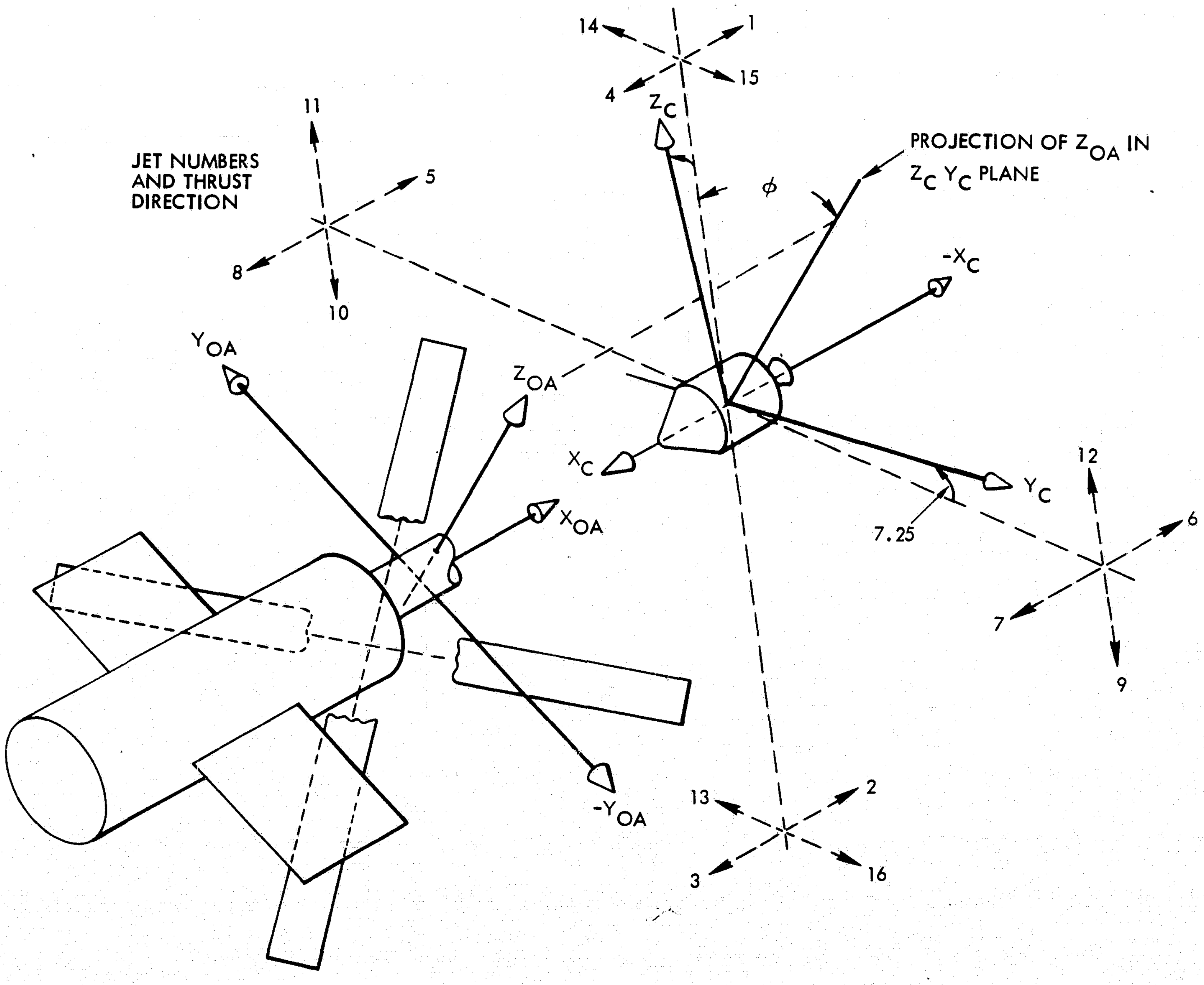
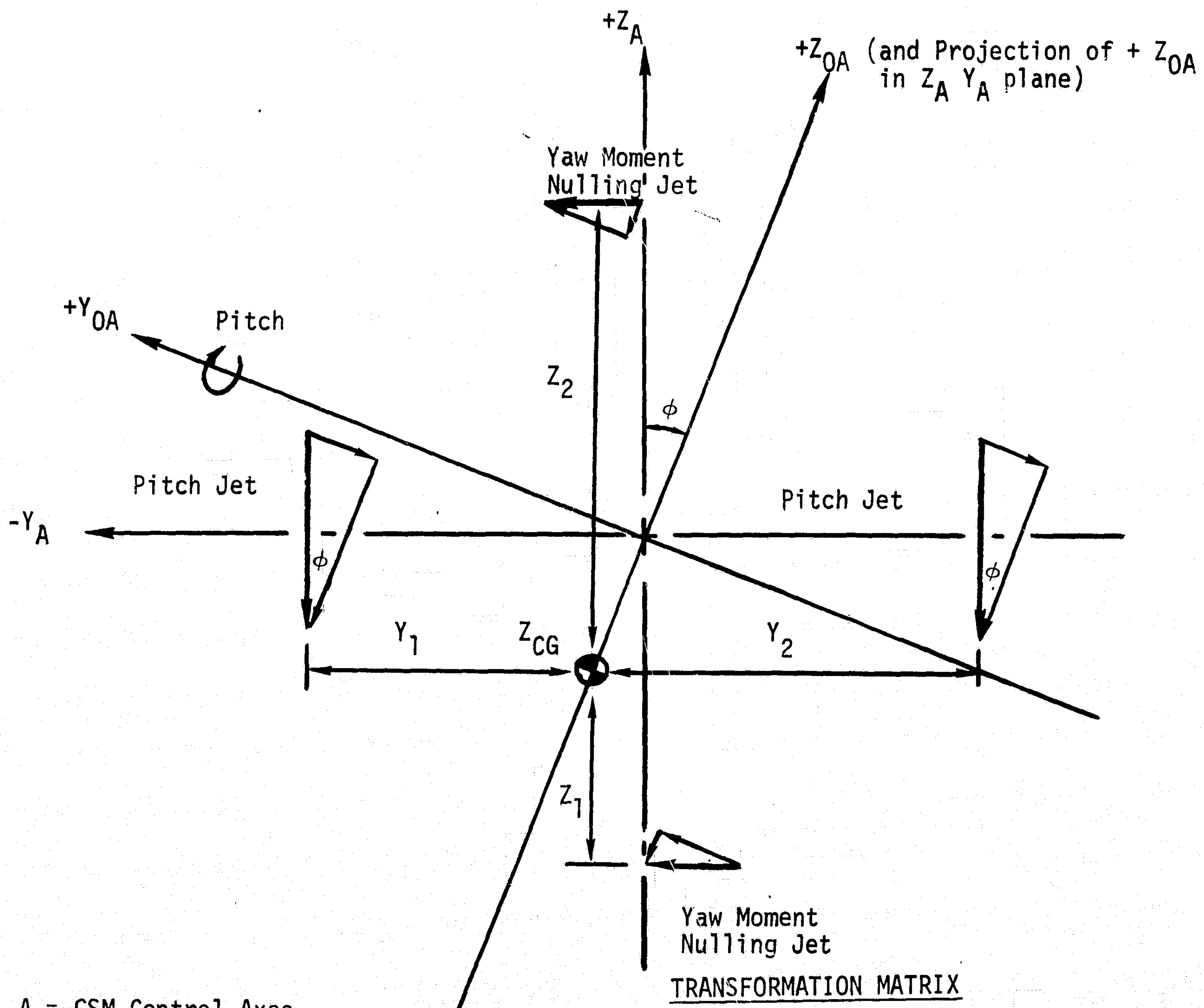


Figure 7 . Location of SM RCS Jets with Respect to OA Axes.



TRANSFORMATION MATRIX

A = CSM Control Axes

OA = Cluster Control Axes

$$\begin{vmatrix} X_{CSM} \\ Y_{CSM} \\ Z_{CSM} \end{vmatrix} = \begin{vmatrix} -1 & 0 & 0 \\ 0 & -\text{COS}\emptyset & \text{SIN}\emptyset \\ 0 & \text{SIN}\emptyset & \text{COS}\emptyset \end{vmatrix} \begin{vmatrix} X_{OA} \\ Y_{OA} \\ Z_{OA} \end{vmatrix}$$

Figure 8 . Orientation of OA Axes with Respect to CSM Axes.

*Note: Ninety-five pounds thrust at zero impulse consumed is worst case condition (equals approximately 100-lb nominal); nonlinear portion of curve is due to propellant cooling between 75°F at lift-off and 10°F in orbit.

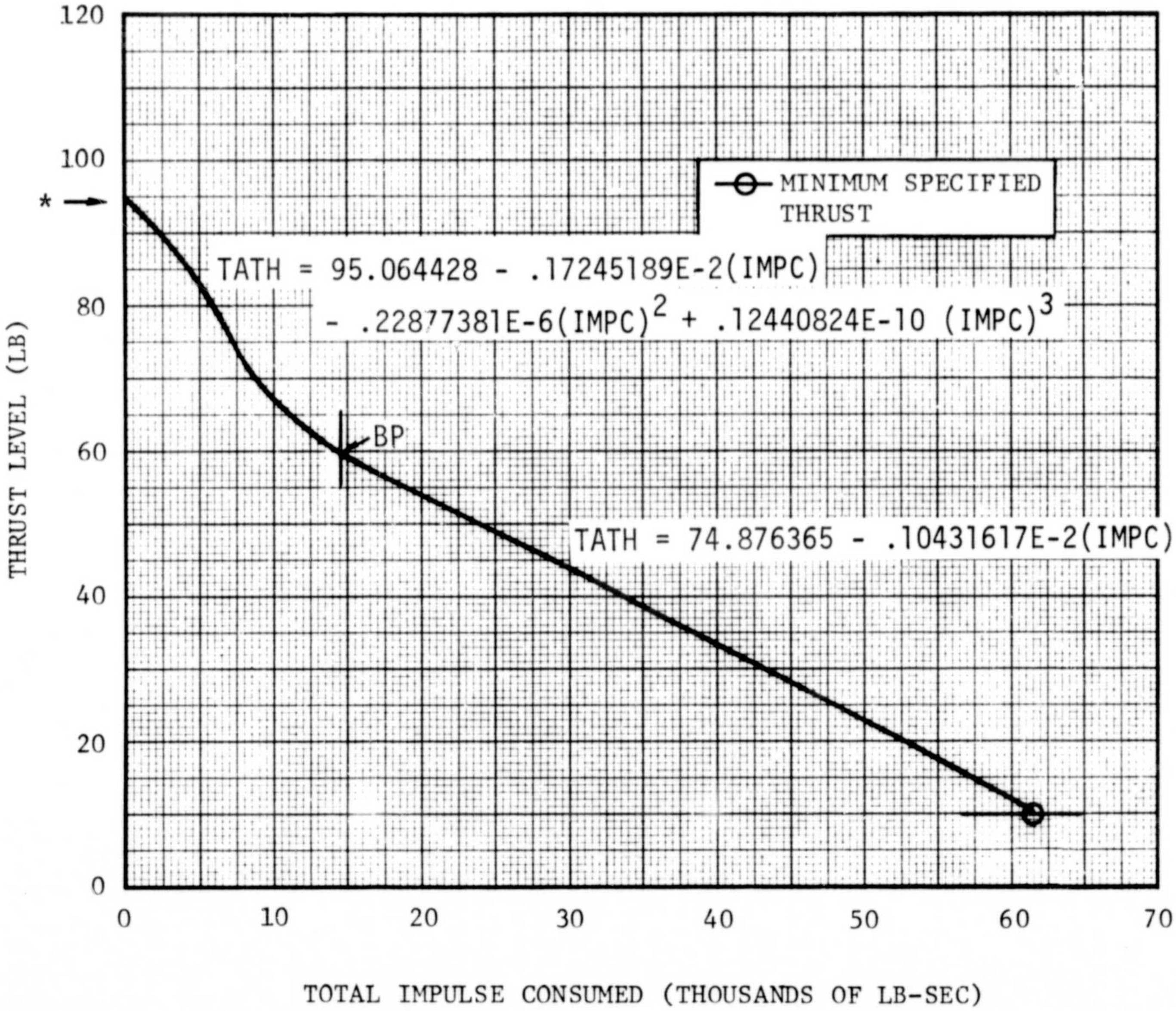


FIGURE 9. TACS Nozzle Thrust vs. Total Impulse Consumed

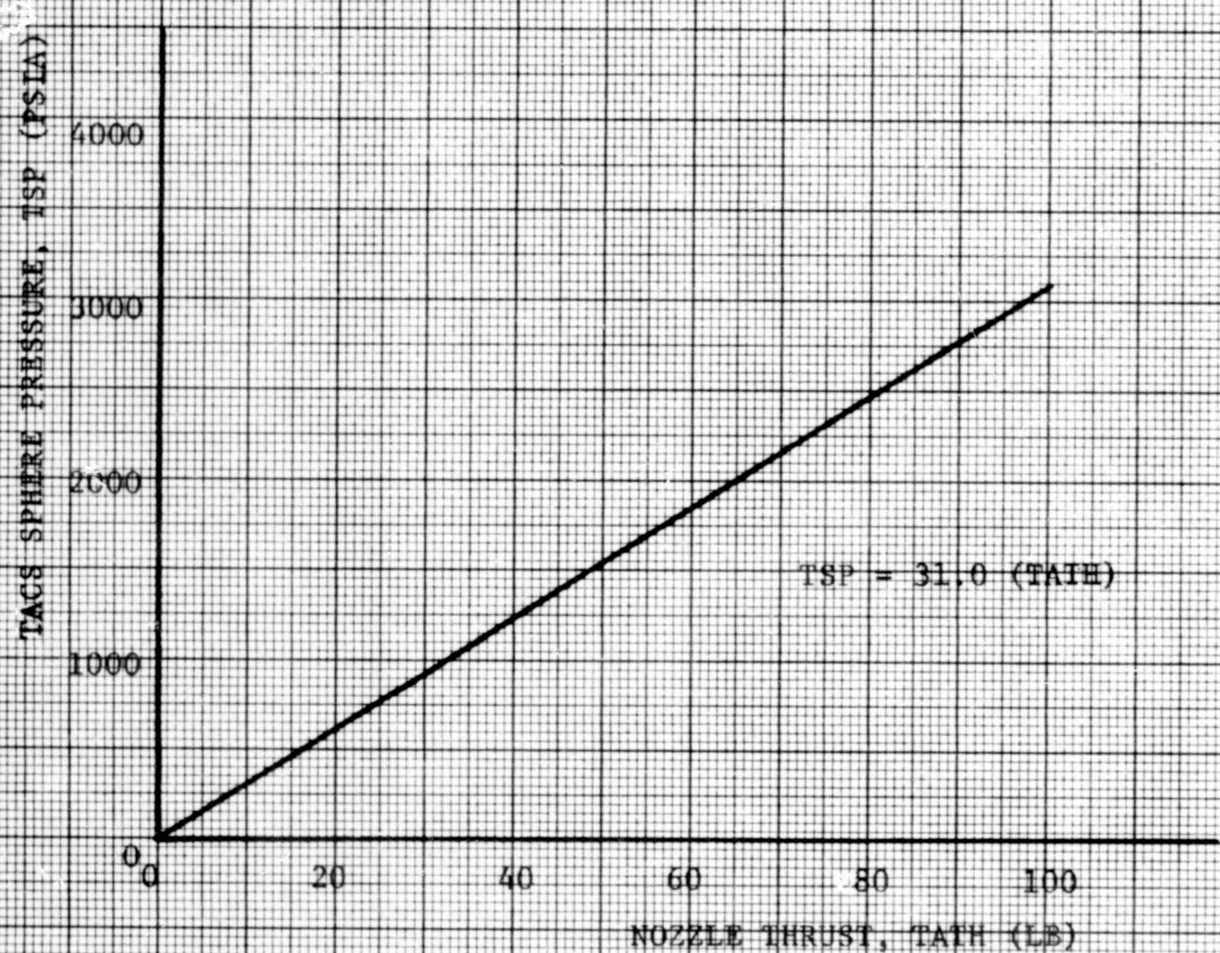


FIGURE 10 TACS SPHERE PRESSURE VS. NOZZLE THRUST

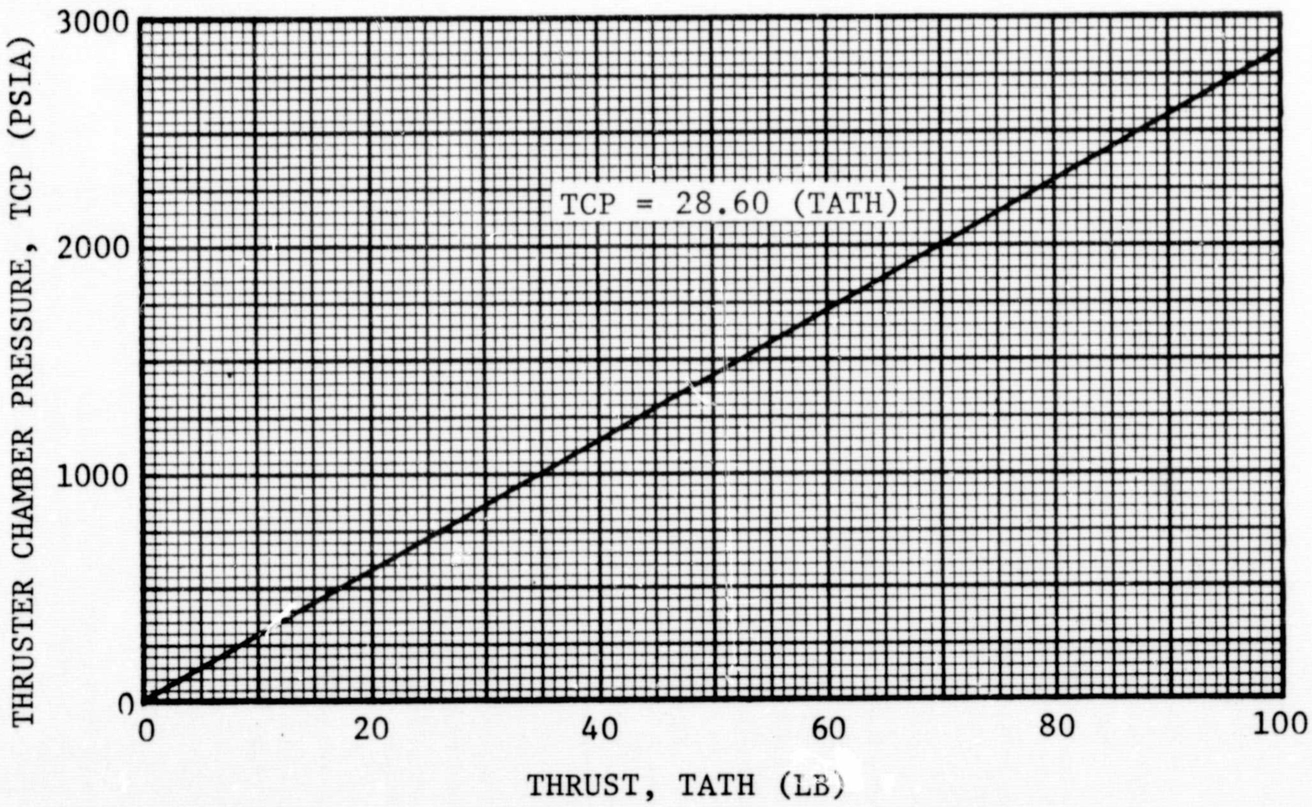


FIGURE 11. TACS NOZZLE CHAMBER PRESSURE VS. NOZZLE THRUST

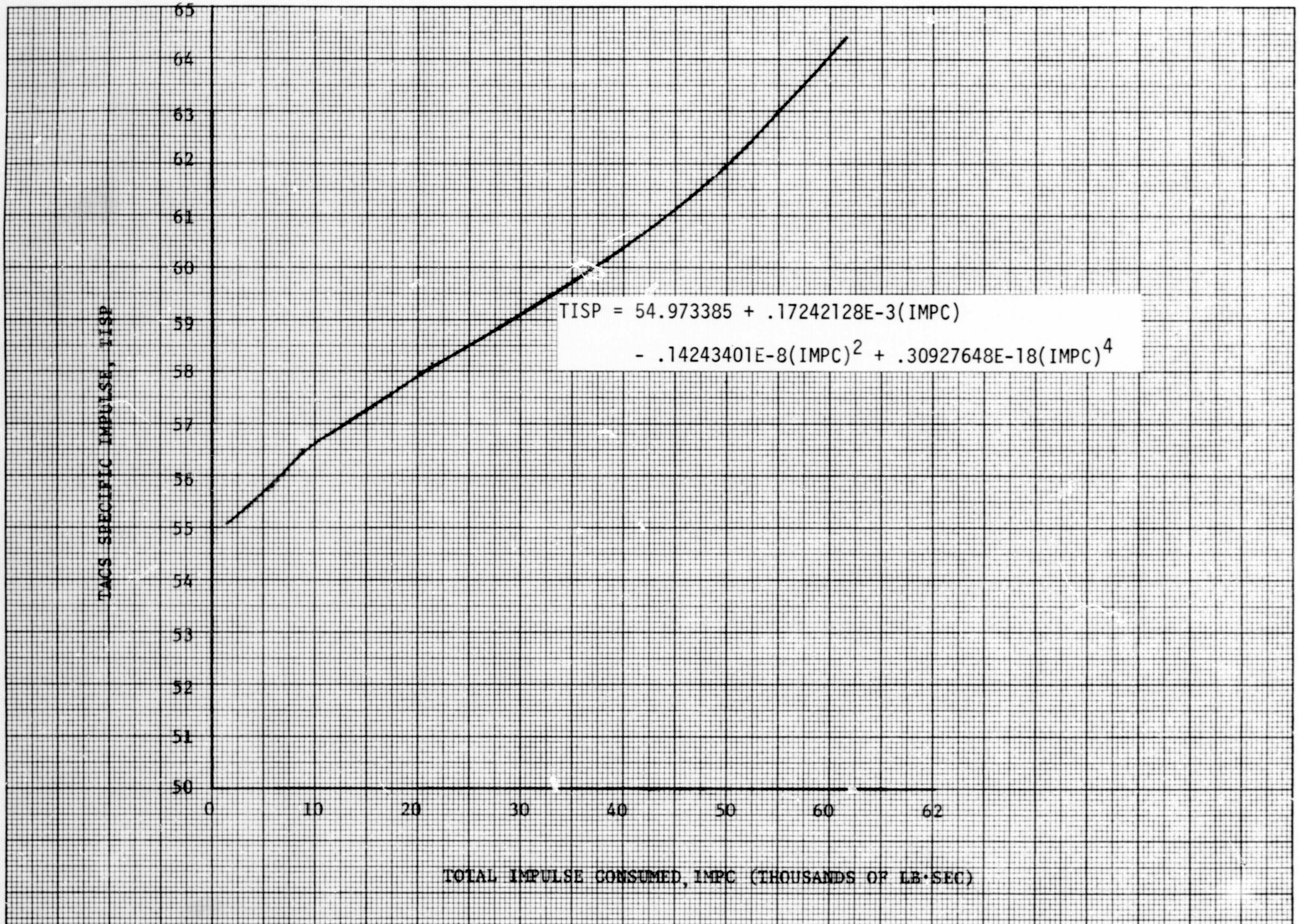


FIGURE 12. TACS SPECIFIC IMPULSE VS TOTAL TACS IMPULSE CONSUMED

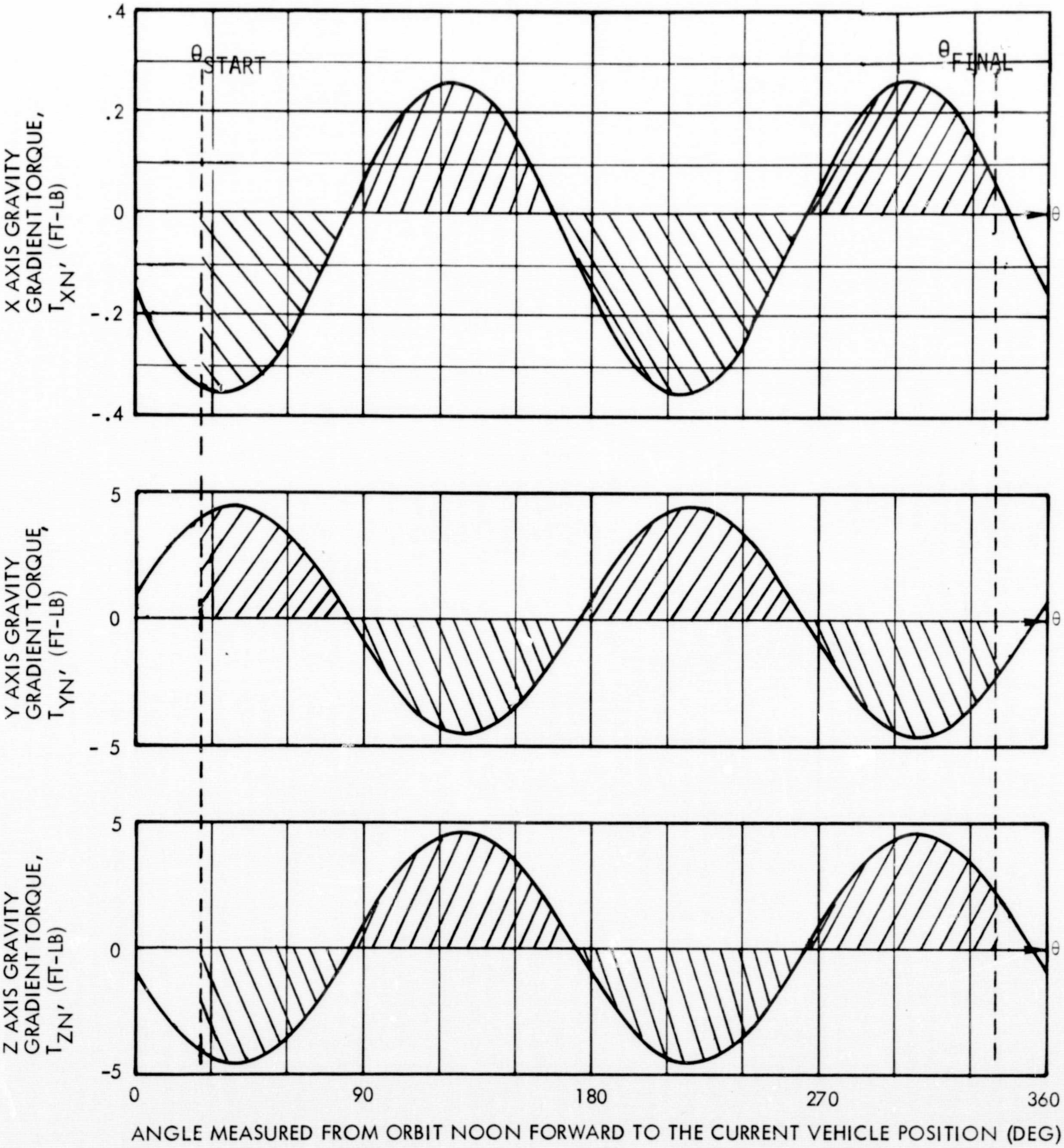


Figure 13. Variation of Gravity Gradient Torques with Orbit Position in SI Attitude (β=45°).

Table 1. Pertinent Equations and Coefficients for TACS-SM RCS Consumables Program

1.0 TACS ONLY ATTITUDE HOLD IMPULSE REQUIREMENTS

1.1 PHASE PLANE LIMIT CYCLE REQUIREMENTS

$$\text{TAHIMPX} = \frac{\Delta H_X}{L_X}\frac{\Delta t_A}{P_X} \quad \text{where} \quad \begin{cases} \dfrac{\Delta H_X}{L_X} = B_1(2)(\Delta T)\left[1 + \dfrac{I_{XY}}{I_{YY}}\dfrac{L_Y}{L_X} + \dfrac{I_{XZ}}{I_{ZZ}}\dfrac{L_Z}{L_X}\right] & \text{lb-sec/cycle} \\ P_X = 4\,\theta_{dbx}\left[\dfrac{I_{XX}}{L_X(\Delta T)(57.29578)} - \dfrac{1}{\dot{\theta}_{dbx}}\right] & \text{sec/cycle} \end{cases}$$

$$\text{TAHIMPY} = \frac{\Delta H_Y}{L_Y}\frac{\Delta t_A}{P_Y} \quad \text{where} \quad \begin{cases} \dfrac{\Delta H_Y}{L_Y} = B_2(2)(\Delta T)\left[\dfrac{I_{YX}}{I_{XX}}\dfrac{L_X}{L_Y} + 1 + \dfrac{I_{YZ}}{I_{ZZ}}\dfrac{L_Z}{L_Y}\right] & \text{lb-sec/cycle} \\ P_X = 4\,\theta_{dby}\left[\dfrac{I_{YY}}{L_Y(\Delta T)(57.29578)} - \dfrac{1}{\dot{\theta}_{dby}}\right] & \text{sec/cycle} \end{cases}$$

$$\text{TAHIMPZ} = \frac{\Delta H_Z}{L_Z}\frac{\Delta t_A}{P_Z} \quad \text{where} \quad \begin{cases} \dfrac{\Delta H_Z}{L_Z} = B_3(2)(\Delta T)\left[\dfrac{I_{ZX}}{I_{XX}}\dfrac{L_X}{L_Z} + \dfrac{I_{ZY}}{I_{YY}}\dfrac{L_Y}{L_Z} + 1\right] & \text{lb-sec/cycle} \\ P_Z = 4\,\theta_{dbz}\left[\dfrac{I_{ZZ}}{L_Z(\Delta T)(57.29578)} - \dfrac{1}{\dot{\theta}_{dbz}}\right] & \text{sec/cycle} \end{cases}$$

$B_1, B_2, B_3 = 1.0$

1.2 TOTAL ATTITUDE HOLD REQUIREMENTS

TTIMPX = TAHIMPX + VTIMPX* + DTIMPX* + ZTIMPX*

TTIMPY = TAHIMPY + VTIMPY* + DTIMPY* + ZTIMPY*

TTIMPZ = TAHIMPZ + VTIMPZ* + DTIMPZ* + ZTIMPZ*

*Computed in other subroutines

2.0 TACS ONLY MANEUVERING IMPULSE REQUIREMENTS

2.1 MANEUVER IMPULSE REQUIREMENTS

$$\text{TMIMPX} = \frac{C_X\, I_{XX}\, |\dot{\theta}_X|}{L_X} + K_X \quad \text{where } \dot{\theta}_X = \frac{\theta_X}{T_M};$$

For class 2 and class 6 maneuvers $\dot{\theta}_X = \dfrac{H_X * 57.29578}{I_{XX}}$

Table 1. (continued)

$$TMIMPY = \frac{C_Y\ I_{YY}\ \dot{\theta}_Y}{L_Y} + \frac{C_1\ I_{YY}\ \Omega_o}{L_Y} + K_Y \quad \text{where } \dot{\theta}_Y = \frac{\theta_Y}{T_M};$$

For class 2 and class 6 maneuvers

$$\dot{\theta}_Y = \frac{H_Y*57.2957}{I_{YY}}$$

$$TMIMPZ = \frac{C_Z\ I_{ZZ}\ \dot{\theta}_Z}{L_Z} + K_Z \quad \text{where } \dot{\theta}_Z = \frac{\theta_Z}{T_M};$$

For class 2 and class 6 maneuvers

$$\dot{\theta}_Z = \frac{H_Z*57.29578}{I_{ZZ}}$$

C_X, C_Y, C_Z = 2.0 for classes 1, 2, 3, and 4; C_X, C_Y, C_Z = 1 for Classes 5 and 6;

K_X, K_Y, K_Z = 0.0 for all classes; C_1 = 1 for Class 4: C_1 = 0 for Classes 1, 2, 3, 5, 6

2.2 TOTAL MANEUVER IMPULSE REQUIREMENTS

TTMIMPX = TMIMPX + TAHIMPX*

TTMIMPY = TMIMPY + TAHIMPY*

TTMIMPZ = TMIMPZ + TAHIMPZ*

* Computed in TACS Only Attitude Hold Subroutine

3.0 SM RCS ATTITUDE HOLD PROPELLANT REQUIREMENTS

3.1 PHASE PLANE LIMIT CYCLE REQUIREMENTS

$$WX = \frac{B_{11}(RA)(NJ)^2 \Delta T_1{}^2\ \Delta t_A}{4\ I_{PX}\ \theta_{dbx}\ I_{SPCSM}} \left[1 + \frac{I_{PXY}}{I_{PY}}\ \frac{PQA}{R_A} + \frac{I_{PXZ}}{I_{PZ}}\ \frac{PQA}{R_A}\right] 57.29578 + C_{11}$$

$$WY = \frac{B_{22}(PQA)(NJ)^2\ \Delta T_1{}^2\ \Delta t_A}{4\ I_{PY}\ \theta_{dby}\ I_{SPCSM}} \left[\frac{I_{PXY}}{I_{PX}}\ \frac{RA}{PQA} + 1 + \frac{I_{PYZ}}{I_{PZ}}\right] 57.29578 + C_{22}$$

$$WZ = \frac{B_{33}\ (PQA)(NJ)^2\ \Delta T_1{}^2\ \Delta t_A}{4\ I_{PZ}\ \theta_{dbz}\ I_{SPCSM}} \left[\frac{I_{PXZ}}{I_{PX}}\ \frac{RA}{PQA} + \frac{I_{PYZ}}{I_{PY}} + 1\right] 57.29578 + C_{33}$$

$PQA = RSIVB + \frac{X_{cg}}{12.}$ where RSIVB = 256.6

$RA = \frac{STR}{12.}$ where STR = 83.

B_{11}, B_{22}, B_{33} = 1.0; C_{11}, C_{22}, C_{33} = 0.0

3.2 TOTAL ATTITUDE HOLD REQUIREMENTS

SMRCSX = VSMRCX* + GSMRCX* + ZSMRCX* + WX

SMRCSY = VSMRCY* + GSMRCY* + ZSMRCY* + WY

SMRCSZ = VSMRCZ* + GSMRCZ* + ZSMRCZ* + WZ

*Computed in other subroutines.

Table 1. (continued)

3.3 QUAD DIVISION OF TOTAL ATTITUDE HOLD PROPELLANT

$$QA = \frac{(SMRCSZ + 0.5\ SMRCSX)}{1 + \frac{Z1}{Z2}}$$

where $Z1 = ST + Z_{cg}\ COS\emptyset$

$Z2 = 2.\ ST - Z1$

$$QC = SMRCSZ + 0.5\ SMRCSX - QA$$

$$QD = \frac{(SMRCSY + 0.5\ SMRCSX)}{1 + \frac{Y1}{Y2}}$$

where $Y1 = ST + Z_{cg}\ SIN\emptyset$

$Y2 = 2.\ ST - Y1$

$$QB = SMRCSY + 0.5\ SMRCSX - QD$$

$\emptyset = 27.5$; $ST = 82.36$

4.0 SM RCS MANEUVER AND TRANSLATION PROPELLANT REQUIREMENTS

4.1 YAW MANEUVER REQUIREMENTS

$$PY = K4\ \left(\frac{2.I_{ZZ}\ \dot{\theta}_Z\ \dot{W}}{TM1} + C4\right)$$

$$PP = K5\ (PY\ (DC) + C5)$$

where $TM1 = 2.(F)\ R\ COS\emptyset + 2.(F)\ R\ (DC)\ SIN\emptyset$

$C4, C5 = 0;\ K4, K5 = 1.$

$F = 102.8$

$\emptyset = 27.5$

$DC = \frac{SIN\emptyset}{COS\emptyset}$

$\dot{W} = 0.371$

$R = \frac{(256.6 + |X_{cg}|)}{12.}$

4.2 PITCH MANEUVER REQUIREMENTS

$$PP = K2\ \left(\frac{2.I_{YY}\ \dot{\theta}_Y\ \dot{W}}{TM1} + C2\right)$$

$$PY = K3\ (PP\ (DC) + C3)$$

where $TM1 = 2.(F)\ R\ COS\emptyset + 2.(F)\ R\ (DC)\ SIN\emptyset$

$C2, C3 = 0;\ K2, K3 = 1.$

$F = 102.8$

$\emptyset = 27.5$

$DC = \frac{SIN\emptyset}{COS\emptyset}$

$\dot{W} = 0.371$

$R = \frac{(256.6 + |X_{cg}|)}{12.}$

Table 1. (continued)

4.3 ROLL MANEUVER REQUIREMENTS

$$PR = K1\left(\frac{2.I_{XX}\,\dot{\theta}_X\,\dot{W}}{RM} + C_1\right)$$

where $RM = 2.F\,\frac{(STR)}{12.}\quad COS\emptyset$

$C_1 = 0;\ K1 = 1.$

$F = 102.8$

$\dot{W} = 0.371$

4.4 QUAD DIVISION OF MANEUVER PROPELLANT

$$QA = \frac{PY}{1+\frac{Z1}{Z2}}$$

$$QC = PY - QA$$

$$QD = \frac{PP}{1+\frac{Y1}{Y2}}$$

$$QB = PP-QD$$

where $Z1 = ST + Z_{cg}\ COS\emptyset$

$Z2 = 2.ST - Z1$

$Y1 = ST + Z_{cg}\ SIN\emptyset$

$Y2 = 2.ST - Y1$

$ST = 82.36$

$\emptyset = 27.5$

For Roll Maneuvers $PY = PP = PR$

4.5 +X TRANSLATION PROPELLANT REQUIREMENTS

$$PT = K6\ \left(\frac{WV*\Delta V}{G(I_{SP})\ COS\alpha} + C6\right)$$

where WV = vehicle weight

ΔV = velocity to be gained

G = gravity constant = 32.17

$I_{SP} = 377.4$

$\alpha = 10°$

$K6 = 1.0;\ C6 = 0.$

4.6 QUAD DIVISION OF TRANSLATION REQUIREMENTS*

4.6.1 Class 6 events

$$QA = 0.5\ \frac{PT}{1+\frac{Z1}{Z2}}$$

$$QC = 0.5\ PT-QA$$

$$QD = \frac{0.5\ PT}{1+\frac{Y1}{Y2}}$$

$$QB = PT-QD$$

4.6.2 Class 7 events

$$QA = \frac{PT}{1+\frac{Z1}{Z2}}$$

$$QC = PT-QA$$

$$QB = 0.0$$

$$QD = 0.0$$

4.6.3 Class 8 events

$$QA = \frac{PT}{1+\frac{Z1}{Z2}}$$

$$QB = PT-QD$$

$$QA = 0.0$$

$$QC = 0.0$$

* See 4.4 for equations for Z1, Z2, Y1, and Y2

Table 1. (continued)

4.7 NESTED CMG/TACS IMPULSE REQUIREMENTS

4.7.1 Nested CMG/TACS Attitude Hold Requirements

4.7.1.1 Local Vertical Attitude

$HXX = (D1)\ 3.\ (\Omega_o)\ I_{YZ}\ (\theta_p - \theta_i)$ where $D1 = 1.$

$HYY = (D2)\ 3.\ (\Omega_o)\ I_{XZ}\ (\theta_p - \theta_i)$ $D2 = 1.$

4.7.1.2 Solar Inertial Attitude

$$\theta_o = \frac{(NTM + 225.)}{57.2958}$$

See zero crossing module for equations for HXX, HYY, HZZ

4.7.2 Nested CMG/TACS Maneuver Requirements

4.7.2.1 Solar Inertial to Local Vertical

For Initial Ramp	For Constant Rate	For Final Ramp
$MH_X = I_{XX}(\dot{\theta}_X)$	HACX = TBD	$MHXS = I_{XX}(-\dot{\theta}_X)$
$MH_Y = I_{YY}(\dot{\theta}_Y)$	HACY = TBD	$MHYS = I_{YY}(-\dot{\theta}_Y - \Omega_o)$
$MH_Z = I_{ZZ}(\dot{\theta}_Z)$	HACZ = TBD	$MHZS = I_{ZZ}(-\dot{\theta}_Z)$

For checking CMG saturation

$$\sqrt{(HXTO)^2 + (HYTO)^2 + (HZTO)^2} < (PER\ )\ HMAX$$

4.7.2.2 Local Vertical to Solar Inertial

For Initial Ramp	For Constant Rate	For Final Ramp
$MH_X = I_{XX}\dot{\theta}_X$	HACX = TBD	$MHXS = I_{XX}(-\dot{\theta}_X)$
$MH_Y = I_{YY}\dot{\theta}_Y$	HACY = TBD	$MHYS = I_{YY}(-\dot{\theta}_Y)$
$MH_Z = I_{ZZ}\dot{\theta}_Z$	HACZ = TBD	$MHZS = I_{ZZ}(-\dot{\theta}_Z)$

For checking CMG saturation see 4.7.2.1.

Table 1. (continued)

4.8 TOTAL TACS IMPULSE CONSUMED AND SM RCS PROPELLANT REMAINING SUBROUTINE

4.8.1 TACS Impulse Consumed Module

4.8.1.1 Thrust

For IMPC > BP

$$TATH = A1\,(IMPC)^3 + A2\,(IMPC)^2 + A3\,(IMPC) + A4$$

For IMPC < BP

$$TATH = X1\,(IMPC) + X2$$

$A1 = .12440824(10^{-10})$

$A2 = -.22877381(10^{-6})$

$A3 = -.0017245189$

$A4 = 95.064428$

$BP = 14.5(10^3)$

$X1 = -.10431617(10^{-2})$

$X2 = 74.876365$

4.8.1.2 Sphere and Chamber Pressure

$$TSP = (C11)\,TATH$$

$$TCP = (D11)\,TATH$$

where $C11 = 31.0$

$D11 = 28.6$

4.8.1.3 Specific Impulse

$$TISP = E1(IMPC)^4 + E2(IMPC)^3 + E3(IMPC)^2 + E4(IMPC) + E5$$

where

$E1 = .30927648(10^{-18})$, $E2=0$, $E3 = -.14243401(10^{-8})$

$E4 = .17242128(10^{-3})$, $E5 = 54.973585$

4.8.2 SM RCS Propellant Consumed Module

4.8.2.1 Fuel and Oxidizer Usage for Event

$$FC = \frac{PC}{1+MR}$$

$$DC = \frac{(PC)MR}{1+MR}$$

where MR = 1.63 for attitude hold

MR = 2.00 for maneuvers

4.8.2.2 Total Usable Propellant Remaining

$$TOTUSEP = (FUEL\ RM)\ 3.05$$

4.8.2.3 Outage

$$OUTA = TOTAL\ PR - TOTUSEP$$

Table 1. (continued)

4.9 PARAMETRIC VARIABLE INITIALIZATION SUBROUTINE

4.9.1 Beta Angle and Orbit Position Module

4.9.1.1 Orbit Rate

$$NBAR = \frac{.07436574}{\left(\frac{RE+H}{RE}\right)^{1.5}} \left[1. + \frac{1.5(.0018228)}{\left(\frac{RE+H}{RE}\right)^{2}} \quad (1. - 1.5\ SIN^2 XI) \right] 57.2958(60)$$

4.9.1.2 Orbit Position

$$\theta_P = (GET - TN)\ NBAR$$

4.9.2 Mass Properties Module

4.9.2.1 Jet Moment Arms

$$L_X = \frac{(RSIVB + Z_{cg})}{12.}$$

$$L_Y = \frac{(|OA34| + X_{cg})}{12.}$$

$$L_Z = \frac{(|OA25| + X_{cg})}{12.}$$

where RSIVB = 132.813

$|OA25| = 771.947$

$|OA34| = 785.825$

4.9.2.2 Mass Properties in CSM Coordinates

$$\begin{vmatrix} I_{PX} & I_{PXY} & I_{PXZ} \\ I_{PXY} & I_{PY} & I_{PYZ} \\ I_{PXZ} & I_{PYZ} & I_{PZ} \end{vmatrix} = \begin{vmatrix} -1 & 0 & 0 \\ 0 & -COS\emptyset & SIN\emptyset \\ 0 & SIN\emptyset & COS\emptyset \end{vmatrix} \begin{vmatrix} I_{XX} & I_{XY} & I_{XZ} \\ I_{XY} & I_{YY} & I_{YZ} \\ I_{XZ} & I_{YZ} & I_{ZZ} \end{vmatrix} \begin{vmatrix} -1 & 0 & 0 \\ 0 & -COS\emptyset & SIN\emptyset \\ 0 & SIN\emptyset & COS\emptyset \end{vmatrix}$$

4.9.3 Maneuver Angle and Maneuver Rate Module

4.9.3.1 Y Axis Rotation Angle

SI to LV

$$\theta_{YP} = \theta_P + (TM)\Omega_o - 0.5\ (TR)\Omega_o$$

LV to SI

$$\theta_{YP} = \theta_P + 0.5\ (TR)\Omega_o$$

Table 1. (continued)

4.9.3.2 Compute Eigenaxis Rotation

$$\theta_R = 2.\ \mathrm{TAN}^{-1}\left(\frac{\mathrm{QLA5}}{\mathrm{QLA4}}\right)$$

$$\text{where } \mathrm{QLA4} = \cos\frac{\theta_{YP}}{2.}\ \cos\frac{\beta}{2}\ \cos\frac{V_Z}{2} + \sin\frac{\theta_{YP}}{2.}\ \sin\frac{\beta}{2}\ \sin\frac{V_Z}{2}$$

$$\mathrm{QLA5} = \sqrt{1-(\mathrm{QLA4})^2}$$

4.9.3.3 Compute Eigenaxis Rotation Rates

$$\dot{\theta}_R = (\mathrm{TW})\ \ddot{\theta}_L$$

$$\text{where } \mathrm{TW} = \frac{\mathrm{TM-TR}}{2} - \sqrt{\frac{(\mathrm{TM-TR})^2}{4} - \frac{\theta_R}{\ddot{\theta}_L}}$$

4.9.3.4 Compute body Rates

$$\dot{\theta}_X = \dot{\theta}_R\, U_{RX} \qquad \text{where } U_{RX} = \frac{\mathrm{QLA1}}{\mathrm{QLA5}}\ (\mathrm{SILV})$$

$$\dot{\theta}_Y = \dot{\theta}_R\, U_{RY} \qquad U_{RY} = \frac{\mathrm{QLA2}}{\mathrm{QLA5}}\ (-\mathrm{SILV})$$

$$\dot{\theta}_Z = \dot{\theta}_R\, U_{RZ} \qquad U_{RZ} = \frac{\mathrm{QLA3}}{\mathrm{QLA5}}\ (\mathrm{SILV})$$

5.0 GRAVITY GRADIENT AND VENTING DISTURBANCE MODULE

5.1 GRAVITY GRADIENT DISTURBANCE MODULE

5.1.1 X Axis Angular Momentum Accumulation due to Gravity Gradient Torques

```
HXT=    ABS(3./4.*OMEGO1*((-S2NZ*(T2MT1-0.5*(S2T2-S2T1))+SBET*C2NZ
*(C2T2-C2T1)+S2NZ*SBET*SBET*(T2MT1+0.5*(S2T2-S2T1)))*PXZ+(2.*SNUZ*
SNUZ*(T2MT1-0.5*(S2T2-S2T1))-S2NZ*SBET*(C2T2-C2T1)+2.*(CNUZ*CNUZ*
SBET*SBET-CBET*CBET)*(T2MT1+0.5*(S2T2-S2T1)))*PYZ+(-SNUZ*CBET*(
C2T2-C2T1)+CNUZ*S2BE*(T2MT1+0.5*(S2T2-S2T1)))*(IZZ-IYY)-(CNUZ*
CBET*(C2T2-C2T1)+SNUZ*S2BE*(T2MT1+0.5*(S2T2-S2T1)))*PXY))
```

5.1.2 Y Axis Angular Momentum Accumulation due to Gravity Gradient Torques

```
HYT=    ABS(3./4.*OMEGO1*((CNUZ*CBET*(C2T2-C2T1)+SNUZ*S2BE*(T2MT1+
0.5*(S2T2-S2T1)))*(IXX-IZZ)+(-SNUZ*CBET*(C2T2-C2T1)+CNUZ*S2BE*(
T2MT1+0.5*(S2T2-S2T1)))*PXY+(2.*(CBET*CBET-SNUZ*SNUZ*SBET*SBET)*(
T2MT1+0.5*(S2T2-S2T1))-2.*CNUZ*CNUZ*(T2MT1-0.5*(S2T2-S2T1))-S2NZ*
SBET*(C2T2-C2T1))*PXZ-(-S2NZ*(T2MT1-0.5*(S2T2-S2T1))+SBET*C2NZ*(
C2T2-C2T1)+S2NZ*SBET*SBET*(T2MT1+0.5*(S2T2-S2T1))))*PYZ))
```

Table 1. (continued)

5.1.3 Z Axis Angular Momentum Accumulation due to Gravity Gradient Torques

```
HZT=    ABS(3./4.*OMEGO1*(2.*(C2NZ*(T2MT1-0.5*(S2T2-S2T1))+S2NZ*
SBET*(C2T2-C2T1)-C2NZ*SBET*SBET*(T2MT1+0.5*(S2T2-S2T1)))*PXY+(-
S2NZ*(T2MT1-0.5*(S2T2-S2T1))+SBET*C2NZ*(C2T2-C2T1)+S2NZ*SBET*SBET*
(T2MT1+0.5*(S2T2-S2T1)))*(IYY-IXX)+(CNUZ*CBET*(C2T2-C2T1)+SNUZ*
S2BE*(T2MT1+0.5*(S2T2-S2T1)))*PYZ-(-SNUZ*CBET*(C2T2-C2T1)+CNUZ*
S2BE*(T2MT1+0.5*(S2T2-S2T1)))*PXZ))
```

where in 5.1.1, 5.1.2, 5.1.3

T2 MT1 = T2-T1; SIN(2T1) = S2T1; SIN(2T2) = S2T2

COS(2T2) = C2T2; COS(2T1) = C2T1; SIN(2NUZ) = S2NZ

SIN(BETA) = SBET; COS(2NUZ) = C2NZ; SIN(NUZ) = SNUZ

COS(BETA) = CBET; COS(NUZ) = CNUZ; VZ = NUZ = NZ

SIN(2BETA) = S2BE; PXZ = IXZ; PYZ = IYZ; PXY = IXY

5.2 VENTING DISTURBANCE MODULE

Compute Venting TACS Impulse Usage

$$VTIMPX = \frac{\int_{ts}^{tf} |VTX| \; dt}{L_X}$$

$$VTIMPY = \frac{\int_{ts}^{tf} |VTY| \; dt}{L_Y}$$

$$VTIMPZ = \frac{\int_{ts}^{tf} |VTZ| \; dt}{L_Z}$$

where VTX = TBS*

VTY = TBS*

VTZ = TBS*

*To be specified.

Table 1. (continued)

5.3 CMG ZEROING MODULE

Compute TACS Impulse for Caging CMG's to Zero Momentum Status

$$ZTIMP_X = \frac{H_{XX}}{L_X}$$

$$ZTIMP_Y = \frac{H_{YY}}{L_Y}$$

$$ZTIMP_Z = \frac{H_{ZZ}}{L_Z}$$

where

$$\begin{aligned}
H_{XX}^{*} = \frac{3}{4}\Omega_0 \Bigg\{ & \Big[- \sin 2\nu_Z \left[(\theta - \theta_0) - \frac{1}{2} (\sin 2\theta - \sin 2\theta_0) \right] \\
& + \sin\beta \cos 2\nu_Z (\cos 2\theta - \cos 2\theta_0) \\
& + \sin 2\nu_Z \sin^2\beta \left[(\theta - \theta_0) + \frac{1}{2} (\sin 2\theta - \sin 2\theta_0) \right] \Big] I_{XZ} \\
& + \Big[2 \sin^2 \nu_Z \left[(\theta - \theta_0) - \frac{1}{2} (\sin 2\theta - \sin 2\theta_0) \right] \\
& - \sin 2\nu_Z \sin\beta (\cos 2\theta - \cos 2\theta_0) \\
& + 2 (\cos^2 \nu_Z \sin^2\beta - \cos^2\beta) \left[(\theta - \theta_0) \right. \\
& \left. + \frac{1}{2} (\sin 2\theta - \sin 2\theta_0) \right] \Big] I_{YZ} \\
& + \Big[- \sin\nu_Z \cos\beta (\cos 2\theta - \cos 2\theta_0) + \cos\nu_Z \sin 2\beta \\
& \left[(\theta - \theta_0) + \frac{1}{2} (\sin 2\theta - \sin 2\theta_0) \right] \Big] (I_{ZZ} - I_{YY}) \\
& - \Big[\cos\nu_Z \cos\beta (\cos 2\theta - \cos 2\theta_0) + \sin\nu_Z \sin 2\beta \\
& \left[(\theta - \theta_0) + \frac{1}{2} (\sin 2\theta - \sin 2\theta_0) \right] \Big] I_{XY} \Bigg\} + K_1 R_1
\end{aligned}$$

Table 1. (continued)

$$
\begin{aligned}
H_{YY}^{*} = \frac{3}{4}\Omega_0 \Bigg\{ \Bigg[& \cos\nu_z \cos\beta \; (\cos 2\theta - \cos 2\theta_0) \\
& + \sin\nu_z \sin 2\beta \left[(\theta-\theta_0) + \frac{1}{2}(\sin 2\theta - \sin 2\theta_0)\right]\Bigg] (I_{XX} - I_{ZZ}) \\
& + \Bigg[- \sin\nu_z \cos\beta \,(\cos 2\theta - \cos 2\theta_0) + \cos\nu_z \sin 2\beta \,[(\theta-\theta_0) \\
& + \frac{1}{2}(\sin 2\theta - \sin 2\theta_0)]\Bigg] I_{XY} \\
& + \Bigg[2(\cos^2\beta - \sin^2\nu_z \sin^2\beta) \left[(\theta-\theta_0) + \frac{1}{2}(\sin 2\theta - \sin 2\theta_0)\right] \\
& - 2\cos^2\nu_z \left[(\theta-\theta_0) - \frac{1}{2}(\sin 2\theta - \sin 2\theta_0)\right] \\
& - \sin 2\nu_z \sin\beta (\cos 2\theta - \cos 2\theta_0)\Bigg] \quad I_{XZ} \\
& - \Bigg[- \sin 2\nu_z \left[(\theta-\theta_0) - \frac{1}{2}(\sin 2\theta - \sin 2\theta_0)\right] \\
& + \sin\beta \cos 2\nu_z \; (\cos 2\theta - \cos 2\theta_0) + \sin 2\nu_z \sin^2\beta [(\theta-\theta_0) \\
& + \frac{1}{2}(\sin 2\theta \; - \sin 2\theta_0)]\Bigg] \quad I_{YZ} \Bigg\} \; + K_2 \; R_2
\end{aligned}
$$

Table 1. (continued)

$$
\begin{aligned}
H^{*}_{ZZ} = \frac{3}{4}\Omega_o \Bigg\{ 2\Big[& \cos 2\nu_z \; [(\theta-\theta_o) - \frac{1}{2}(\sin 2\theta - \sin 2\theta_o)] \\
& + \sin 2\nu_z \sin\beta (\cos 2\theta - \cos 2\theta_o) - \cos 2\nu_z \sin^2\beta[(\theta-\theta_o) \\
& + \frac{1}{2}(\sin 2\theta - \sin 2\theta_o)]\Big] \; I_{XY} \\
& + \Big[- \sin 2\nu_z \; [(\theta-\theta_o) - \frac{1}{2}(\sin 2\theta - \sin 2\theta_o)] \\
& + \sin\beta \cos 2\nu_z \; (\cos 2\theta - \cos 2\theta_o) + \sin 2\nu_z \sin^2\beta[(\theta-\theta_o) \\
& + \frac{1}{2}(\sin 2\theta - \sin 2\theta_o)]\Big] \; (I_{YY} - I_{XX}) \\
& + \Big[\cos\nu_z \cos\beta (\cos 2\theta - \cos 2\theta_o) + \sin\nu_z \sin 2\beta [(\theta-\theta_o) \\
& + \frac{1}{2}(\sin 2\theta - \sin 2\theta_o)]\Big] \quad I_{YZ} \\
& - \Big[-\sin\nu_z \cos\beta (\cos 2\theta - \cos 2\theta_o) + \cos\nu_z \sin 2\beta[(\theta-\theta_o) \\
& + \frac{1}{2}(\sin 2\theta - \sin 2\theta_o)]\Big] \quad I_{XZ} \Bigg\} + K_3 \cdot R_3 .
\end{aligned}
$$

TABLE 2. EVENT CATEGORIES, TYPES, AND CLASSES

EVENT CATEGORY	EVENT TYPE	CLASS 1	CLASS 2	CLASS 3	CLASS 4	CLASS 5	CLASS 6	CLASS 7	CLASS 8
TACS ONLY CONTROL	1 TACS ONLY ATT. HOLD	ATM CONTROL Δt_A, ICAGE, IPAR, IATT, GET, CONFIG.	I.U. CONTROL Δt_A, ICAGE, IPAR, IATT, GET, CONFIG						
	2 TACS ONLY MNVR	MNVR. RATES KNOWN $\dot{\theta}_X, \dot{\theta}_Y, \dot{\theta}_Z$, ICAGE, CONFIG GET, MNVR, ATM	MNVR ANGLES & TIME KNOWN $\theta_X, \theta_Y, \theta_Z$, TM ICAGE, CONFIG, GET, MNVR, ATM	EIGENAXIS RATES KNOWN $\epsilon_X, \epsilon_Y, \epsilon_Z$, CONFIG, GET, ICAGE, ATM, MNVR	SI OR LV EIGENAXIS MVR TM, GET, ICAGE, CONFIG, ATM, SILV	NULLING/ADD-ING KNOWN RATE $\dot{\theta}_X, \dot{\theta}_Y, \dot{\theta}_Z$, GET CONFIG, ATM	MNVR ANG. MOMENT. KNOWN H_X, H_Y, H_Z, GET, CONFIG, ATM		
CMG/TACS NESTED CONTROL	3 NESTED	SI OR LV EIGENAXIS MVR SILV, TM, GET	SI OR LV ATT HOLD Δt_A, IATT, IPAR, CONFIG, GET						
SM RCS CONTROL	4 SM RCS ATT HOLD	SI OR LV ATT HOLD db_x, db_y, db_z Δt_A, IPAR, ICAGE, IATT GET, CONFIG.							
	5 SM RCS MNVR & TRANSLATION	ROLL MNVR $\dot{\theta}_X$, MNVR, GET, CONFIG.	YAW MNVR $\dot{\theta}_Z$, MNVR, GET, CONFIG.	PITCH MNVR $\dot{\theta}_Y$, MNVR, GET, CONFIG.	SI OR LV EIGENAXIS MVR TM, GET, ICAGE, CONFIG, SILV	EIGENAXIS RATES KNOWN $\epsilon_X, \epsilon_Y, \epsilon_Z$, GET, CONFIG, ICAGE, MNVR	4 JET XLATION ΔV, GET CONFIG	2 JET XLATION QUADS A/C ΔV, GET, CONFIG	2 JET XLATION QUADS B/D ΔV, GET CONFIG
SPECIAL EVENTS	6 SPECIAL EVENTS	TACS, IMPULSE DEBIT GET, EIMPT	SM RCS DEBIT GET, MR, QUAD A, QUAD B, QUAD C, QUAD D						

TABLE 3. TACS THRUSTER TORQUES

TACS THRUSTER	TORQUE		
	X_V AXIS	Z_V AXIS	Y_V AXIS
1			+
4			-
3	+	-	
2	-	+	
5	+	+	
6	-	-	

TABLE 4. DATA FOR ATM AND I.U. SKYLAB PHASE PLANE

MODE OF CONTROL	ATTITUDE ERROR DEADBAND	RATE CROSSOVER POINT	RATE LEDGE	MINIMUM* IMPULSE BIT
I.U.	3°, 2°, 2°	.2°/sec	.3°/sec	10.0 lb.sec.
ATM	.5°,.5°,.5°	.05°/sec	.1°/sec	7.5 lb.sec.

*Variable

Table 5

YZ Force Control Jet Select Logic

Maneuver	Jets	
	Primary	Nulling
+ Pitch	11(D1), 12(B2)	15(C1), 16(A2)
- Pitch	9(B1), 10(D2)	13(A1), 14(C2)
+ Yaw	15(C1), 16(A2)	9(B1), 10(D2)
- Yaw	13(A1), 14(C2)	11(D1), 12(B2)
+ Roll AC	14(C2), 16(A2)	N/R*
+ Roll BD	10(D2), 12(B2)	N/R
- Roll AC	13(A1), 15(C1)	N/R
- Roll BD	9(B1), 11(D1)	N/R

*Not required.

APPENDIX A

Appendix A presents samples of the computer print output for the TACS-SM RCS Consumables Program. Table A-1 shows the mission independent initialization data required by the program to calculate the trajectory data. Tables A-2 and A-3 show the sample print output for TACS only attitude hold and maneuver events. Table A-4 presents the sample print output for SM RCS attitude hold events.

The output report presents the data in three parts. First, the trajectory data and mass properties are displayed based on GET and the OWS configurations. Second, the TACS usage is displayed for the event in question. Third, the cumulative totals are shown. The cumulative totals contain information which is used by the program to update the variable TACS parameters, e.g., thrust, I_{SP}, and to initialize for the calculation of TACS usage for the next event.

THE FOLLOWING VARIABLES ARE CONSIDERED CONSTANT DURING THIS DATA CASE:

AZ.....ORIENTATION PARAMETER AT INSERTION..............................	.00000000	DEG
DL.....ORIENTATION PARAMETER AT INSERTION..............................	.00000000	DEG
E......ANGLE BETWEEN EQUATOR AND ECLIPTIC PLANE........................	.23450000+02	DEG
GAMMO..SUN POSITION AT INSERTION.......................................	.00000000	DEG
GAMO...LOCATION OF SUN AT JANUARY 0, 1972..............................	.27964936+03	DEG
H......ORBIT HEIGHT..	.23500000+03	NAUTICAL MILES
PHI....ORBIT INSERTION LATITUDE..	.39467000+02	DEG
RE.....RADIUS OF EARTH...	.34439336+04	NAUTICAL MILES
THETO..SIDEREAL TIME JANUARY 0, 1972...................................	.99415183+02	DEG
TINS...TIME FROM LIFTOFF TO ORBIT INSERTION............................	.16222500+00	HOURS
U......ORIENTATION PARAMETER AT INSERTION..............................	.00000000	DEG
XI.....ORBIT INCLINATION WITH RESPECT TO EQUATOR.......................	.50000000+02	DEG
XLE....LONGITUDE OF INSERTION MERIDIAN.................................	-.66160009+02	DEG
XLST...LOCAL SIDEREAL TIME OF THE INSERTION MERIDIAN...................	.00000000	DEG
XOMEGO.RIGHT ASCENSION OF ASCENDING NODE AT ORBIT INSERTION............	.00000000	DEG
DAY....TIME OF ORBIT INSERTION IN DAYS PAST JANUARY 0, 1972............	.31461092+03	DAYS

TABLE A-1 MISSION INDEPENDENT INITIALIZATION DATA

TRAJECTORY DATA

GET DAYS	HR	MIN	SEC	REV	BETA (DEG)	THETAO (DEG)	ORBIT POS (DEG)	ORBIT RATE (DEG/SEC)	ORBIT POS AT SUNSET (DEG)	THETA DOT X (DEG/SEC)	THETA DOT Y (DEG/SEC)	THETA DOT Z (DEG/SEC)	ATT HOLD TIME(SEC)
0	1	11	1.723	0	60.540	.000	-110.181	.064	135.634	.0000	.0000	.0000	2178.000

OWS CONFIGURATION ID AND DESCRIPTION 6 - SL-1/2 OA CONFIGURATION

OWS MASS PROPERTIES - OWS COORDINATES

WEIGHT (LBS)	XCG (IN)	YCG (IN)	ZCG (IN)	IXX (SLUG-FT2)	IYY (SLUG-FT2)	IZZ (SLUG-FT2)	IXY (SLUG-FT2)	IXZ (SLUG-FT2)	IYZ (SLUG-FT2)
172168.9	-228.0	-2.5	-26.6	651368.8	4139114.4	4072600.2	11724.2	243485.5	-22833.7

EVENT DESCRIPTION - 1 AXIS ATT HOLD
TACS ONLY ATTITUDE HOLD -- IATT=1 -- SI -- ATM CONTROL

TACS EVENT SUB TOTALS

EVENT MIB (LB-SEC)		TOTAL IMPULSE PER AXIS(LB-SEC)	IMPULSE PER AXIS DUE TO;		VENTING (LB-SEC)		AERODYNAMICS (LB-SEC)		ATTITUDE HOLD (LB-SEC)		GRAVITY GRADIENT (LB-SEC)		OWS MANEUVER (LB-SEC)		ZEROING CMGS (LB-SEC)
7.5000	X	123.368		X	.000	X	.000	X	67.287	X	56.081	X	.000	X	.000
	Y	129.018		Y	.000	Y	.000	Y	40.708	Y	88.310	Y	.000	Y	.000
	Z	202.481		Z	.000	Z	.000	Z	45.352	Z	157.129	Z	.000	Z	.000
EVENT TOT.		454.868	TOTALS PER AXIS		.000		.000		153.347		301.521		.000		.000
EVENT GN2		8.268													

CUMULATIVE TOTALS

TACS

	CONSUMED	CURRENT
IMPULSE	454.868 LB-SEC	60545.132 LB-SEC
GN2	8.268 LBS	1075.732 LBS
THRUST		94.234 LBS
ISP		55.052 SEC
PRESSURE		2921.249 LBS/IN2
TEMPERATURE		70.000 DEG F.
M.I.L.		7.444 LB-SEC

SM-RCS

QUADS	EVENT PROP	PROP TODATE	PROP REMAINING
A	.00 LBS	.00 LBS	300.00 LBS
B	.00 LBS	.00 LBS	300.00 LBS
C	.00 LBS	.00 LBS	300.00 LBS
D	.00 LBS	.00 LBS	300.00 LBS
TOT	.00 LBS	.00 LBS	1200.00 LBS

TAC CHAMBER PRESSURE.........	2695.088	LBS/IN2
AVERAGE ISP..................	55.012	SEC
TOT USABLE RCS PROP REMAIN...	1200.000	LBS
TOT RCS FUEL CONSUMED........	.000	LBS
TOT RCS OXIDIZER CONSUMED....	.000	LBS
TOT RCS FUEL REMAINING.......	393.443	LBS
TOT RCS OXIDIZER REMAINING...	806.557	LBS
TOT RCS PROPELLANT REMAINING.	1200.000	LBS
MIXTURE RATIO................	2.000	
AVERAGE MIXTURE RATIO........	.000	
OUTAGE DUE TO MIXTURE RATIO..	.000	LBS
CUMULATIVE OUTAGE............	.000	LBS

TABLE A-2 OUTPUT FORMAT FOR TACS ONLY ATTITUDE HOLD EVENTS

TRAJECTORY DATA

GLT DAYS	HR	MN	SEC	REV	BETA (DEG)	THETAO (DEG)	ORBIT POS (DEG)	ORBIT RATE (DEG/SEC)	ORBIT POS AT SUNSET (DEG)	THETA DOT X (DEG/SEC)	THETA DOT Y (DEG/SEC)	THETA DOT Z (DEG/SEC)	MANEUVER TIME(SEC)
0	1	11	1.723	0	60.540	.000	-110.181	.064	135.634	-.1151	.1120	-.0579	728.201

OWS CONFIGURATION ID AND DESCRIPTION 8 - SL-1/2 OA CONFIGURATION

OWS MASS PROPERTIES - OWS COORDINATES

WEIGHT (LBS)	XCG (IN)	YCG (IN)	ZCG (IN)	IXX (SLUG-FT2)	IYY (SLUG-FT2)	IZZ (SLUG-FT2)	IXY (SLUG-FT2)	IXZ (SLUG-FT2)	IYZ (SLUG-FT2)
172168.?	-228.0	-2.5	-26.6	651368.8	4139114.4	4072600.2	11724.2	243485.5	-22833.7

EVENT DESCRIPTION - 1 AXIS MANEUVER
TACS ONLY MANEUVER -------- SI EIGENAXIS MANEUVER

TACS EVENT SUB TOTALS

EVENT M I B (LB-SEC)		TOTAL IMPULSE PER AXIS(LB-SEC)	IMPULSE PER AXIS DUE TO:		VENTING (LB-SEC)		AERODYNAMICS (LB-SEC)		ATTITUDE HOLD (LB-SEC)		GRAVITY GRADIENT (LB-SEC)		OWS MANEUVER (LB-SEC)		ZEROING CMGS (LB-SEC)
7.5000	X	316.134		X	.000	X	.000	X	22.497	X	.000	X	295.637	X	.000
	Y	473.098		Y	.000	Y	.000	Y	13.610	Y	.000	Y	459.488	Y	.000
	Z	192.225		Z	.000	Z	.000	Z	15.163	Z	.000	Z	177.062	Z	.000
EVENT TOT.		983.457	TOTALS PER AXIS		.000		.000		51.271		.000		932.187		.000
EVENT GN2		17.668													

CUMULATIVE TOTALS

TACS

	CONSUMED	CURRENT
IMPULSE	4642.074 LB-SEC	54357.929 LB-SEC
GN2	83.849 LBS	1000.151 LBS
THRUST		83.374 LBS
ISP		55.743 SEC
PRESSURE		2584.586 LBS/IN2
TEMPERATURE		70.000 DEG F.
M.I.B.		6.587 LB-SEC

SM-RCS

QUADS	EVENT PROP	PROP TODATE	PROP REMAINING
A	.00 LBS	.00 LBS	300.00 LBS
B	.00 LBS	.00 LBS	300.00 LBS
C	.00 LBS	.00 LBS	300.00 LBS
D	.00 LBS	.00 LBS	300.00 LBS
TOT	.00 LBS	.00 LBS	1200.00 LBS

TAC CHAMBER PRESSURE.........	2384.489	LBS/IN2
AVERAGE ISP..................	55.664	SEC
TOT USABLE RCS PROP REMAIN...	1200.000	LBS
TOT RCS FUEL CONSUMED........	.000	LBS
TOT RCS OXIDIZER CONSUMED....	.000	LBS
TOT RCS FUEL REMAINING.......	393.443	LBS
TOT RCS OXIDIZER REMAINING...	806.557	LBS
TOT RCS PROPELLANT REMAINING.	1200.000	LBS
MIXTURE RATIO................	2.000	
AVERAGE MIXTURE RATIO........	.000	
OUTAGE DUE TO MIXTURE RATIO..	.000	LBS
CUMULATIVE OUTAGE............	.000	LBS

TABLE A-3 OUTPUT FORMAT FOR TACS ONLY MANEUVER EVENTS

TRAJECTORY DATA

GET DAYS	HR	MI	SEC	REV	BETA (DEG)	THETAO (DEG)	ORBIT POS (DEG)	ORBIT RATE (DEG/SEC)	ORBIT POS AT SUNSET (DEG)	THETA DOT X (DEG/SEC)	THETA DOT Y (DEG/SEC)	THETA DOT Z (DEG/SEC)	ATT HOLD TIME(SEC)
0	1	11	1.723	0	62.540	.030	-110.181	.064	135.634	.0000	.0000	.0000	2178.000

OWS CONFIGURATION ID AND DESCRIPTION 8 - 3L-1/2 OA CONFIGURATION

OWS MASS PROPERTIES - SM COORDINATES

WEIGHT (LBS)	XCG (IN)	YCG (IN)	ZCG (IN)	IXX (SLUG-FT2)	IYY (SLUG-FT2)	IZZ (SLUG-FT2)	IXY (SLUG-FT2)	IXZ (SLUG-FT2)	IYZ (SLUG-FT2)
172168.9	-228.0	-2.5	-26.6	651368.8	4143561.6	4058052.8	-101836.4	-221476.9	-14079.8

EVENT DESCRIPTION - 1 AXIS ATT HOLD
SM ATTITUDE HOLD IATT=1

SMRCS EVENT SUB TOTALS

EVENT M I B (LB-SEC)		TOTAL IMPULSE PER AXIS(LB-SEC)	IMPULSE PER AXIS DUE TO;		VENTING (LB-SEC)		AERODYNAMICS (LB-SEC)		ATTITUDE HOLD (LB-SEC)		GRAVITY GRADIENT (LB-SEC)		OWS MANEUVER (LB-SEC)		ZEROING CMGS (LB-SEC)
1.0000	X	.535		X	.000	X	.000	X	.095	X	.440	X	.000	X	.000
	Y	1.113		Y	.000	Y	.000	Y	.061	Y	1.052	Y	.000	Y	.000
	Z	.768		Z	.000	Z	.000	Z	.065	Z	.703	Z	.000	Z	.000
EVENT TOT.		2.417	TOTALS PER AXIS		.000		.000		.221		2.196		.000		.000
EVENT GN2		.000													

CUMULATIVE TOTALS

TACS

	CONSUMED	CURRENT
IMPULSE	7122.859 LB-SEC	53877.145 LB-SEC
GN2	128.198 LBS	955.802 LBS
THRUST		75.670 LBS
ISP		56.130 SEC
PRESSURE		2345.767 LBS/IN2
TEMPERATURE		70.000 DEG F.
M.I.B.		5.978 LB-SEC

SM-RCS

QUADS	EVENT PROP	PROP TODATE	PROP REMAINING
A	.67 LBS	.67 LBS	299.33 LBS
B	.59 LBS	.59 LBS	299.41 LBS
C	.37 LBS	.37 LBS	299.63 LBS
D	.79 LBS	.79 LBS	299.21 LBS
TOT	2.42 LBS	2.42 LBS	1197.58 LBS

TAC CHAMBER PRESSURE.........	2164.159	LBS/IN2
AVERAGE ISP.................	56.098	SEC
TOT USABLE RCS PROP REMAIN...	1197.543	LBS
TOT RCS FUEL CONSUMED........	.806	LBS
TOT RCS OXIDIZER CONSUMED....	1.611	LBS
TOT RCS FUEL REMAINING.......	392.637	LBS
TOT RCS OXIDIZER REMAINING...	804.946	LBS
TOT RCS PROPELLANT REMAINING.	1197.583	LBS
MIXTURE RATIO................	2.000	
AVERAGE MIXTURE RATIO........	2.000	
OUTAGE DUE TO MIXTURE RATIO..	.040	LBS
CUMULATIVE OUTAGE............	.040	LBS

TABLE A-4 OUTPUT FORMAT FOR SM RCS ATTITUDE HOLD EVENTS

TRAJECTORY DATA

GET DAYS HR MN SEC	REV	BETA (DEG)	THETAO (DEG)	ORBIT POS (DEG)	ORBIT RATE (DEG/SEC)	ORBIT POS AT SUNSET (DEG)	THETA DOT X (DEG/SEC)	THETA DOT Y (DEG/SEC)	THETA DOT Z (DEG/SEC)	MANEUVER TIME(SEC)
0 1 11 1.723	0	60.540	.000	-110.181	.064	135.634	.0100	.0000	.0000	.0000

OWS CONFIGURATION ID AND DESCRIPTION 8 = SL-1/2 OA CONFIGURATION

OWS MASS PROPERTIES - OWS COORDINATES

WEIGHT (LBS)	XCG (IN)	YCG (IN)	ZCG (IN)	IXX (SLUG-FT2)	IYY (SLUG-FT2)	IZZ (SLUG-FT2)	IXY (SLUG-FT2)	IXZ (SLUG-FT2)	IYZ (SLUG-FT2)
172166.9	-228.0	-2.5	-26.6	651368.8	4139114.4	4072600.2	11724.2	243485.5	-22833.7

EVENT DESCRIPTION - 1 AXIS MANEUVER
SM MANEUVER ROLL

SMRCS EVENT SUB TOTALS

EVENT M I B (LB-SEC)		TOTAL IMPULSE PER AXIS(LB-SEC)	IMPULSE PER AXIS DUE TO,	VENTING (LB-SEC)		AERODYNAMICS (LB-SEC)		ATTITUDE HOLD (LB-SEC)		GRAVITY GRADIENT (LB-SEC)		OWS MANEUVER (LB-SEC)		ZEROING CMGS (LB-SEC)
1.0000	X	.000		X	.000	X	.000	X	.000	X	.000	X	.000	X	.000
	Y	.000		Y	.000	Y	.000	Y	.000	Y	.000	Y	.000	Y	.000
	Z	.000		Z	.000	Z	.000	Z	.000	Z	.000	Z	.000	Z	.000
EVENT TOT.		.000	TOTALS PER AXIS		.000		.000		.000		.000		.000		.000
EVENT GN2		.000													

CUMULATIVE TOTALS

TACS

	CONSUMED	CURRENT
IMPULSE	7122.859 LB-SEC	53877.145 LB-SEC
GN2	128.198 LBS	955.802 LBS
THRUST		75.670 LBS
ISP		56.130 SEC
PRESSURE		2345.767 LBS/IN2
TEMPERATURE		70.000 DEG F.
M.I.B.		5.978 LB-SEC

SM-RCS

QUADS	EVENT PROP	PROP TODATE	PROP REMAINING
A	.02 LBS	.98 LBS	299.02 LBS
B	.01 LBS	.85 LBS	299.15 LBS
C	.01 LBS	.54 LBS	299.46 LBS
D	.02 LBS	1.14 LBS	298.86 LBS
TOT	.07 LBS	3.50 LBS	1196.50 LBS

TAC CHAMBER PRESSURE.........	2164.159	LBS/IN2
AVERAGE ISP..................	56.098	SEC
TOT USABLE RCS PROP REMAIN...	1196.397	LBS
TOT RCS FUEL CONSUMED........	1.181	LBS
TOT RCS OXIDIZER CONSUMED....	2.322	LBS
TOT RCS FUEL REMAINING.......	392.261	LBS
TOT RCS OXIDIZER REMAINING...	804.235	LBS
TOT RCS PROPELLANT REMAINING.	1196.497	LBS
MIXTURE RATIO................	1.630	
AVERAGE MIXTURE RATIO........	1.966	
OUTAGE DUE TO MIXTURE RATIO..	.100	LBS
CUMULATIVE OUTAGE............	.282	LBS

TABLE A-5 OUTPUT FORMAT FOR SM RCS MANEUVER EVENTS

REFERENCES

1. "Apollo Telescope Mount Digital Computer (ATMDC) Program Definition Document (PDD), Part 1," IBM Federal Systems Division, IBM No. 70-207-0002, dated November 4, 1970.

2. Skylab Program Operational Data Book, Vol. II, December 1970, MSC-01549.

3. MSC Internal Note No. 70-FM-160, "Preliminary Program Description and Flow Diagram of the TACS-SM RCS Consumables Program," dated 10 November 1970.

4. NASA Memorandum 70-FM74-327, "Flow Diagram and Equations for the TACS Only Maneuvering Subroutine for the MOPS/ASP Propulsion Model (RCS/TACS Consumables Budgeting Model)" dated 10 December 1970.

5. "Flow Diagram and Equations for the Parametric Variable Initialization Subroutine,: T. M. Osmer, dated 17 December 1970, TRW IOC 70:7254.A-142.

6. "TACS Only Attitude Hold Subroutine and Driver Flow Diagrams," T. M. Osmer, dated 28 Jaunary 1971, Attachment 1 of TRW IOC 71:7254.A-9.

7. "SM RCS Attitude Hold Subroutine," T. M. Osmer, dated 18 February 1971, TRW IOC 71:7254.A-17.

8. "Total TACS Impulse Consumed and SM RCS Propellant Remaining Subroutine," T. M. Osmer, dated 25 February 1971, TRW IOC 71:7254.A-26.

9. "Preliminary CMG-TACS Nested Subroutine," T. M. Osmer, 19 March 1971, TRW IOC 71:7254.A-32.

10. NASA Memorandum FM 74 (71-114)"TACS and SM RCS Consumables Computer Program",dated 23 April 1971.

11. NASA Memorandum FM 74 (71-172), "Skylab TACS Data-Propellant Consumption for TACS Only Attitude Hold Control Mode, dated 15 June 1971.